WATER QUALITY AND THE FIRST-FLUSH EFFECT IN ROOF-BASED RAINWATER HARVESTING

By

JESSICA JEANETTE LAY

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WATER QUALITY AND THE FIRST-FLUSH EFFECT

IN ROOF-BASED RAINWATER HARVESTING

Thesis Approved:

Dr. Jason R. Vogel

Thesis Adviser

Dr. Jason B. Belden

Dr. Glenn O. Brown

Dr. Daniel E. Storm

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Abstract: Rainwater harvesting (RWH) is a low impact development practice that involves the capture, diversion and storage of rainwater for later use. RWH can help alleviate demands on public water supply systems and promote better conservation practices in the public. Incorporating a first-flush diversion in a RWH system can drastically improve the water quality of harvested rainwater. The objectives of this research were to (1) evaluate the water quality of roof runoff from asphalt shingle, clay tile, metal, and tar and gravel roofs, (2) quantify a first-flush diversion based on a mass removal of pollutants, (3) evaluate a first-flush occurrence in roof runoff based on continuous conductivity measurements throughout a storm event, and (4) perform a pilot-study to determine if soils had potential for long-term accumulation of polycyclic aromatic hydrocarbons (PAHs) when watered with roof runoff that had no first-flush diversion. All runoff samples met "good" and "excellent" Oklahoma irrigation water-quality guidelines for conductivity, sodium adsorption ratio, and boron concentrations. While present, PAH concentrations in runoff samples were observed to be three orders of magnitude below recommended Health Based Screening Levels. An upper-confidence limit was constructed using the binomial probability density function to determine the minimum first-flush diversion required to obtain a 50, 75, 90, and 95% mass removal of total suspended solids and PAHs. Results from the soil pilot study indicated that there is potential for long-term accumulation of PAHs in soils receiving roof runoff that has no first-flush diversion. Approximately 70% of the soil samples that received roof runoff had higher PAH concentrations than the paired soil samples that did not receive roof runoff. Twenty-four to 100% of soil samples were also observed to exceed minimum human-health risk-based screening levels for individual PAH compounds in residential soils. Using harvested rainwater from rooftops to water lawns or irrigate gardens can potentially lead to long-term accumulation of PAHs in the soils when a first-flush diversion is neglected. Therefore, it is recommended that an appropriate first-flush diversion be included in a RWH collection system in order to reduce this potential of accumulation and improve the overall water quality of the harvested rainwater.

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CHAPTER 1

INTRODUCTION

Rainwater harvesting (RWH) involves the capture, diversion, and storage of rainwater for later use. RWH is a low impact development stormwater best management practice that can also aid in reducing stormwater runoff volume. Roof-based rainwater harvesting is gaining popularity world-wide and is implemented in both developed and developing countries for non-potable and potable use. However, the water quality of the harvested rainwater is of great concern to end users, as roof runoff has been identified as a source of nonpoint source pollution Van Metre and Mahler (2003).

The majority of a rooftop's dust and debris are believed to be washed away during the initial periods of a rainfall event, a phenomenon known as the first flush. In order to improve the water quality of harvested rainwater, many researchers have called for the diversion of the first flush to be included in a RWH collection system. Research has shown that diverting the first flush can greatly improve the overall water quality of the harvested rainwater (Mendez et al. 2011, Doyle and Shanahan 2012, Martinson and Thomas 2005, Förster 1999). Recommendations for first-flush diversions have been made based on reducing turbidity, fecal and total coliforms, and to generally remove dust and leaves after a long dry period (Pacey and Cullis 1986, Martinson and Thomas 2005, Doyle and Shanahan 2012, TWDB 2005). The research presented in this thesis evaluated the water-quality of roof runoff using Oklahoma irrigation water-quality guidelines as the harvested rainwater may be used for watering lawns or irrigating gardens. Water samples were also analyzed for the presence of polycyclic aromatic hydrocarbons (PAHs), phosphorus flame retardants (PFRs),flame retardants (PFRs), and pyrethroid insecticides. These organic compounds have been observed in urban and roof runoff and are contaminants of concern due to their toxicity, mutagenicity, carcinogenicity, and bioaccumulation potential (Haritash and Kaushik 2009, Van Metre and Mahler 2003, Förster 1999, Regnery and Püttmann 2010, Fries and Puttmann 2003, van der Veen and de Boer 2012, Weston et al. 2009). Based on results for total suspended solids (TSS) and PAH concentrations in the water samples, first-flush diversion recommendations were created based on mass removals of these pollutants. As PAHs have the potential for long-term accumulation in soils, a pilot-study was also performed on analyzing soils located beneath roof downspouts for PAH concentrations.

1.1 Objectives

The objectives of this research were to (1) evaluate the water quality of roof runoff from different roofing materials based on irrigation water-quality guidelines for Oklahoma as well as for metals, TSS, turbidity, PAHs, PFRs, and pyrethroid insecticides, (2) quantify a first-flush diversion based on mass removals of TSS and PAHs, (3) evaluate a first-flush occurrence in roof runoff based on continuous electrical conductivity (EC) measurements throughout a storm event, and (4) perform a pilot-study to evaluate soils for potential long-term accumulation of PAHs when watered with roof runoff that has no first-flush diversion.

1.2. Organization of Thesis

Chapter 2 presents research on the overall water-quality of the roof runoff based on Oklahoma irrigation water-quality guidelines as well as on dissolved metal (Fe, Cu, Zn, and Mn), TSS, turbidity, PAH, PFR, and pyrethroid insecticide concentrations. Runoff samples were collected from both constructed metal, asphalt shingle, and clay tile roofs during three simulated storm events in Stillwater, OK. Commercial metal and tar and gravel buildings, and one constructed asphalt shingle roof, were sampled during actual storm events in Oklahoma City, OK.

Chapter 3 presents research over the first-flush effects observed during the simulated and actual storm events. Recommended first-flush diversions based on mass removals of TSS and PAHs are discussed in this chapter. Results from the pilot-study evaluating soils receiving roof runoff for long-term PAH accumulations are also presented.

Chapter 4 presents a summary of conclusions from Chapters 2 and 3 and suggestions for future work. Appendix A contains the water-quality results for all samples from the simulated rainfall events. Appendix B contains the water-quality results for all samples from the Oklahoma City field sampling events. Appendix C contains data from the pilot study on PAH accumulations in soils. Appendix D includes data related to the continuous conductivity measurements in Oklahoma City. Appendix E contains results from the Spearman's rho correlation testing performed on the rainfall simulation and Oklahoma City samples.

CHAPTER 2

ROOF-RUNOFF WATER QUALITY

2.1 Abstract

As rainwater harvesting gains popularity world-wide, the quality of the roof runoff is of concern for end-users. Three simulated (SIM) rainfall events (64, 38, and 28 mm/hr intensities) were performed on 18 constructed roofs representing six asphalt shingle, six metal, and six clay tile roofs in Stillwater, Oklahoma (OK). These roofs were oriented north-south and east-west in equal parts to determine if orientation to prevailing winds had a significant impact on water quality. Runoff samples from eleven storm events were collected in 2012 from three roofs representing tar and gravel, metal, and asphalt shingles in Oklahoma City (OKC), OK. Samples from both sites were analyzed for pH, electrical conductivity (EC), nitrate-nitrogen, boron, sodium adsorption ratio (SAR), Fe, Cu, Zn, Mn, total suspended solids (TSS), and turbidity, as well as for the presence of polycyclic aromatic hydrocarbons (PAHs), phosphorus flame retardants tris(2-chloroethyl) phosphate (TCEP) and tris(1,3-dichloro-2-propyl)phosphate (TDCPP), and pyrethroid insecticides bifenthrin, cypermethrin, and lambda-cyhalothrin. Field samples collected in OKC were also analyzed for the presence of total coliform and *E. coli* bacteria.

Significant differences ($\alpha = 0.05$) between sequential samples were observed for nearly all parameters and constituents analyzed in SIM samples, indicating the presence of a first flush. Significant differences ($\alpha = 0.05$) were also observed based on simulation intensity. There was no significance difference ($\alpha = 0.05$) in runoff water quality between north-south and east-west SIM

roofs. Significant differences (α = 0.05) were observed between roof types at the OKC site; however it was difficult to determine significant differences between samples taken at different runoff depths. This was attributed to the varying intensities in rainfall that occurred during a storm event in OKC as opposed to the SIM roofs that received a constant intensity throughout each event.

Roof runoff did not exceed Oklahoma irrigation water-quality guidelines for EC, SAR, or boron in any of the SIM or OKC discrete-samples. At the 90th percentile, total coliform concentrations at ranged between 1652 to >2419 CFU/100 mL while *E. coli* concentrations were observed to range between 1.1 to 396 CFU/100 mL in OKC samples. The tar and gravel roof had the worst concentrations of bacteria in its runoff, followed by the asphalt shingle, then the metal roof. No trend was observed between bacteria concentrations and roof type or runoff depth.

PAHs were observed in up to 42% of SIM samples and up to 84% of all OKC samples. While present at trace levels (ng/L), concentrations never exceeded Health Based Screening Levels for the compounds. The 90th percentile of $\sum$17PAHs for SIM samples were 735, 559, and 497 ng/L for asphalt shingle, metal, and clay tile roofs, respectively. The 90th percentile of $\sum$17PAHs for OKC field samples were 1440, 517, and 391 ng/L for asphalt shingle, metal, and tar and gravel roofs, respectively. TCEP and TDCPP were in 3% and 27% of SIM samples, respectively, and 23% of OKC samples. Lambda-cyhalothrin was undetected in SIM samples and detected in 7% of OKC samples. Bifenthrin was detected in <1% of SIM samples and undetected in OKC samples. Cypermethrin was not detected in either SIM or OKC samples. Atmospheric deposition was observed to be the main contributor of pollutants in the roof runoff.

2.2 Introduction

2.2.1 Roof-Runoff Water Quality

Roof runoff is considered to play a significant role in contributing to and being a pathway for nonpoint source pollution in urban runoff (Van Metre and Mahler 2003, Clark et al. 2008).

Metals, cations, and nutrients can be leached from the roofing material (Chang et al. 2004, Clark et al. 2008, Nicholson et al. 2009). While the roofing material itself can be a source of pollutants, atmospheric deposition is often the main contributor of pollutants in roof runoff (Lye 2009, Van Metre and Mahler 2003, Egodawatta et al. 2009, Förster 1999, Thomas and Green 1993, Rocher et al. 2004).

As rainwater harvesting (RWH) gains popularity world-wide, as both a non-potable and potable source of water, the quality of the roof runoff is of concern for end users. Elevated concentrations of zinc in roof runoff can have detrimental effects on local ecosystems (Schriewer et al. 2008). Metal concentrations are also of concern when utilizing harvested rainwater for irrigation purposes, as there is potential for metal buildup in the uppermost soil layer (Nicholson et al. 2009). In Australia, areas with very low population densities rely on roof-based rainwater harvesting as the primary source of drinking water (Kus et al. 2010). Rooftop rainwater harvesting is also a means of potable water supply in many developing countries (Meera and Ahammed 2006). When using harvested rainwater as a potable source of water, heavy metals, trace organic pollutants, and microbiological contamination are of great concern for end users (Meera and Ahammed 2006). There are many variables that affect the overall water quality in harvested rainwater including roof type, age, location (i.e. urban, rural), care and maintenance, industrial treatments, local climate, orientation and slope, atmospheric pollution, antecedent dry period, and surrounding vegetation (Farreny et al. 2011, Ward et al. 2013, Chang et al. 2004, Mendez et al. 2011, de Kwaadsteniet et al. 2013). Numerous studies have been performed on researching the water quality in roof runoff, as summarized by Farreny et al. (2011).

2.2.2 Organic Contaminants of Concern

Polycyclic aromatic hydrocarbons (PAHs) are ubiquitous in the environment, composed of two or more fused benzene rings, and are formed primarily through the incomplete combustion of biomass and fossil fuel (Lima et al. 2005). PAHs are of environmental concern due to their detrimental biological effects, toxicity, mutagenicity, carcinogenicity, and their bioaccumulation potential (Haritash and Kaushik 2009). PAHs are hydrophobic compounds that can sorb onto particulates, which may then be transported by water on suspended sediment or through the air on dust particles (Van Metre et al. 2000). Numerous studies have observed PAHs in urban runoff (Brown and Peake 2006, Grynkiewicz et al. 2002, Hwang and Foster 2006, Stein et al. 2006, Van Dolah et al. 2005), including roof runoff (Mendez et al. 2011, Van Metre and Mahler 2003, Förster 1999, Rocher et al. 2004). Table 2-1 lists the physicochemical properties of the 16 USEPA priority PAH compounds and the PAH 2-methylnapthalene.

Table 2-1. Physicochemical properties of the phosphorus flame retardants tris(2-chloroethyl) phosphate, tris(1,3-dichloro-2-propyl)phosphate, and pyrethroid insecticides bifenthrin, cypermethrin, and lambda-cyhalothrin.

Compound Name	**CAS No.**	**No. of rings**	**Molecular weight g/mole**	**Water solubility mg/L**
Naphthalene	91-20-3	2	128.2	31.0
2-Methylnaphthalene	91-57-6	2	142.2	24.6
Acenaphthylene	208-96-8	3	152.2	16.1
Acenaphthene	83-32-9	3	154.2	3.90
Fluorene	86-73-7	3	166.2	1.89
Phenanthrene	85-01-8	3	178.2	1.15
Anthracene	120-12-7	3	178.2	0.043
Fluoranthene	206-44-0	4	202.3	0.26
Pyrene	129-00-0	4	202.3	0.14
Benz(*a*)anthracene	56-55-3	4	228.3	$9.4x10^{-3}$
Chrysene	218-01-9	4	228.3	$2.0x10^{-3}$
Benzo(*b*)fluoranthene	205-99-2	5	252.3	$1.5x10^{-3}$
Benzo(*k*)fluoranthene	207-08-9	5	252.3	$0.8x10^{-3}$
Benzo(*a*)pyrene	50-32-8	5	252.3	$1.6x10^{-3}$
Dibenz(*a,h*)anthracene	53-70-3	5	278.4	$5.0x10^{-4}$
Benzo(*g,h,i*)perylene	191-24-2	6	276.3	$2.6x10^{-4}$
Ideno(1,2,3-*cd*)pyrene	193-39-5	6	276.3	-

Adapted **(Ingvertsen et al. 2011)**. Other sources: **(EPA 2003, Yan et al. 2004)**.

Phosphorus flame retardants (PFRs) are also contaminants of concern observed in urban runoff, including roof runoff (Regnery and Püttmann 2010, Fries and Puttmann 2003). PFRs were proposed as alternatives to brominated flame retardants (BFRs) due to BFRs persistence and toxicity in the environment and bioaccumulative properties (van der Veen and de Boer 2012).

However, PFRs have shown to exhibit some of the same characteristics as BFRs. Tris(2-chloroethyl) phosphate (TCEP) is a chlorinated PFR and plasticizer used in PVC, cellulose, coatings, polyester resins, textiles, and polyurethane foam (van der Veen and de Boer 2012). TCEP has toxic effects to aquatic organisms and has been identified as a potential human carcinogen by the European Union (EU) (Regnery and Püttmann 2010). While TCEP has slowly been phased out of use, it is still present in the environment (Regnery and Püttmann 2010). Tris(1,3-dichloro-2-propyl)phosphate (TDCPP) is another chlorinated PFR found in plastic, textiles, and polyurethane foam (van der Veen and de Boer 2012). TDCPP has limited degradation in natural waters and meets criteria to be persistent or very persistent in the environment by the EU, yet does not meet criteria of being bioaccumulative or toxic in the environment (van der Veen and de Boer 2012). Concentrations of TDCPP were observed in rainfall and lakes in Italy, where it was hypothesized that atmospheric deposition was the cause for pollution (Bacaloni et al. 2008).

Pyrethroid insecticides are synthetic chemicals commonly used for pest control in urban environments by both professionals and consumers (Weston et al. 2009, He et al. 2008). Due to their wide-spread use, pyrethroids, such as bifenthrin and cypermethrin, have been observed in residential urban runoff at concentrations exceeding toxicity thresholds for sensitive invertebrates (Weston et al. 2009). However, the concentrations do not necessarily come from rooftop runoff. Nevertheless, atmospheric deposition of the insecticides onto rooftops during application on residential properties can potentially occur. Research has shown that insecticide residues can remain on rough surfaces, such as concrete, for prolonged periods of time, allowing for extended contamination of runoff (Jiang et al. 2010). Rough surfaces surrounding residential homes may also translate to rough rooftop surfaces (i.e. asphalt shingles). Lambda-cyhalothrin is another pyrethroid insecticide of concern due to its wide-spread use and potential impact on aquatic ecosystems (He et al. 2008). Table 2-2 lists the physicochemical properties of TCEP, TDCPP, bifenthrin, cypermethrin, and lambda-cyhalothrin.

Table 2-2. Physicochemical properties of the phosphorus flame retardants tris(2-chloroethyl) phosphate, tris(1,3-dichloro-2-propyl)phosphate, and pyrethroid insecticides bifenthrin, cypermethrin, and lambda-cyhalothrin.

Compound Name	CAS No.	Molecular weight g/mole	Water solubility mg/L
Tris(2-chloroethyl)phosphate (TCEP)	115-96-8	285.5	7.82×10^3
Tris(1,3-dichloro-2-propyl)phosphate (TDCPP)	13674-87-8	430.9	1.50
Bifenthrin	82657-04-3	422.9	0.1
Cypermethrin	52315-07-8	416.3	-
Lambda-cyhalothrin	91465-08-6	449.9	0.005
Sources:**(van der Veen and de Boer 2012, Sigma-Aldrich 2014, Taylor and Di Marco 2003, He et al. 2008)**			

2.2.3 Objective

The objective of this research was to evaluate the water quality of roof runoff based on Oklahoma irrigation water-quality guidelines, as well as on dissolved metal (Fe, Cu, Zn, and Mn), TSS, turbidity, PAH, PFR, and pyrethroid insecticide concentrations. Runoff samples were evaluated from asphalt shingles, metal, clay tile, and tar and gravel roofing materials.

2.3 Materials and Methods

2.3.1 Study Sites

The study was conducted at two sites in Oklahoma: the Oklahoma State University (OSU) Agronomy Farm in Stillwater and the OSU Oklahoma City (OKC) campus. The Agronomy Farm was located approximately 300 meters north of Highway 51, right on the edge of town, and the OKC site was located approximately 200 meters west of Interstate 44 (I – 44), in the middle of the city. Simulated rainfall events (SIM) were performed at the Agronomy Farm, while field samples were collected from actual storm events at OKC.

2.3.2 Rainfall Simulations

Eighteen simulated roof structures (1.67 m^2 catchment area) were constructed and placed at the Agronomy Farm in June 2011 (Figure 2-1). New Elite Glass-Seal® three tab asphalt shingles (Tamko®, Joplin, MO), new MasterRib® acrylic coated Galvalume Plus® metal sheeting (Severstal Sparrows Point, LLC, Sparrows Point, MD), and 60 year-old clay tiles (Reddick Roofing and Guttering, Enid, OK) were installed on the structures and replicated six times each. Nine roofs, consisting of three replicates of each roofing material, were oriented north-south (NS) while the remaining nine roofs were oriented east-west (EW). This was done in order to determine if roof orientation in relation to the prevailing wind direction had a significant impact on the water quality.

Figure 2-1. Eighteen constructed roof structures representing metal, asphalt shingle, and clay tile roofing materials used in the simulated rainfall events study.

A portable rainfall simulator was built to simulate natural rainfall events on the constructed roofs. Previous research by Shelton et al. (1985) showed that a 50 WSQ nozzle was capable of producing drops within 2% of terminal velocity when placed three meters high at 28 kPa operating nozzle pressure. This same nozzle was later used in designing a portable rainfall simulator for field work in another study as it was able to maintain critical intensity, distribution, and energy characteristic of natural rainfall (Humphry et al. 2002). The WSQ nozzle emits a wide, square spray pattern, which was needed for this study to adequately rain onto two roofs at the same time.

Three different spray nozzles were tested and used for the rainfall simulations: a 30 WSQ, 24 WSQ, and 14 WSQ nozzle (Spraying Systems Co., Wheaton, Il). Uniformity tests were performed on each nozzle prior to the field simulations to determine the average intensity and uniformity provided by each nozzle at a pressure of 34 kPa. The 30, 24, and 14 WSQ nozzles produced an average intensity of 64, 38, and 28 mm/hr, respectively.

Tap water that had been filtered through a reverse osmosis (RO) filter was used for the simulations. This was done in an attempt to mimic natural rainwater conditions in the simulation events. The treated water was stored in a 3785 L plastic tank attached to a trailer. The rainfall simulator consisted of a PVC constructed boom, fitted with the three separate nozzles, and raised three meters into the air via square metal tubing attached to the trailer. Water was pumped from the tank through vinyl tubing to the boom. The boom and desired nozzle were centered over the roofs during a simulation. In order to minimize interference from the wind on the spray pattern, a 4.6 m wind block was constructed and erected around the roofs during a simulation event (Figure 2-2).

Figure 2-2. The portable rainfall simulator placement and wind block used for the simulated rainfall events.

Vinyl gutters were installed on both sides of each roof and given an appropriate slope that allowed the runoff to drain in one direction. Teflon-lined tubing connected to a PVC funnel hanging at the lower end of each gutter directed the runoff into sampling bottles during the simulations.

2.3.2.1 Simulation Sample Collection

Six samples were manually collected from each roof during the three simulated rainfall events. The 64 mm/hr simulation was performed for 21 minutes and 21 seconds, which corresponded to the time it took to completely fill all six sample bottles from the metal roofs. The 38 and 28 mm/hr intensity rainfall simulations were both performed for 30 minutes each. The first five samples were 2 L each and collected in glass amber bottles; the sixth (final) samples varied in volume from 10 to 36.2 L, depending on the rainfall intensity and roofing material, and were collected into a 36.2 L glass carboys. Samples were split in the field into separate bottles and placed on ice in coolers until sample processing could occur. The glass bottles and lids used for sample collections were thoroughly cleaned prior to use with laboratory-grade soap, three acetone rinses, and three rinses with a 10% nitric acid solution (bottles only) followed by deionized water. The bottles and lids were allowed to air dry before use.

The three intensity simulation events were performed separately; the 64 mm/hr simulation occurred in August 2011, 38 mm/hr simulation in November 2011, and the 28 mm/hr simulation in February 2012. Each rainfall simulation (per intensity) was conducted over a period of two days. For the 64 and 38 mm/hr simulations, the NS structures were sampled on the first day and the EW structures on the second day. The 28 mm/hr simulation had the order of the roofs sampled reversed due to field conditions. Due to the limits of the spray coverage from the nozzles, only two roofs were sampled at a time. This resulted in a total of five simulations each day over the two day period per intensity. An antecedent dry period (ADP) of 8 days was observed for the NS structures on the

64 and 38 mm/hr simulations and 9 days ADP for the EW structures. The 28 mm/hr simulation had an ADP of 8 days for the E-W and 9 days for the NS structures.

2.3.3 Field Sampling in Oklahoma City

Two full-scale commercial and one constructed roof were sampled at OKC: a 29-year-old flat tar and gravel roof, an eight-year-old metal roof, and an approximately one-year old asphalt shingle roof. The roofs had contributing catchment areas of 92, 88, and 9.3 m^2, respectively. The asphalt shingle roof was constructed on site strictly for research purposes and placed near the tar and gravel roof. The tar and gravel roof had never been resurfaced since its original construction in 1983 (Edwards 2011). Figure 2-3 is an aerial map showing where the roofs were located relative to I-44. The metal roof was located within 100 m of the tar and gravel and asphalt shingle roofs; the tar and gravel roof was approximately 17 m from the asphalt shingle roof.

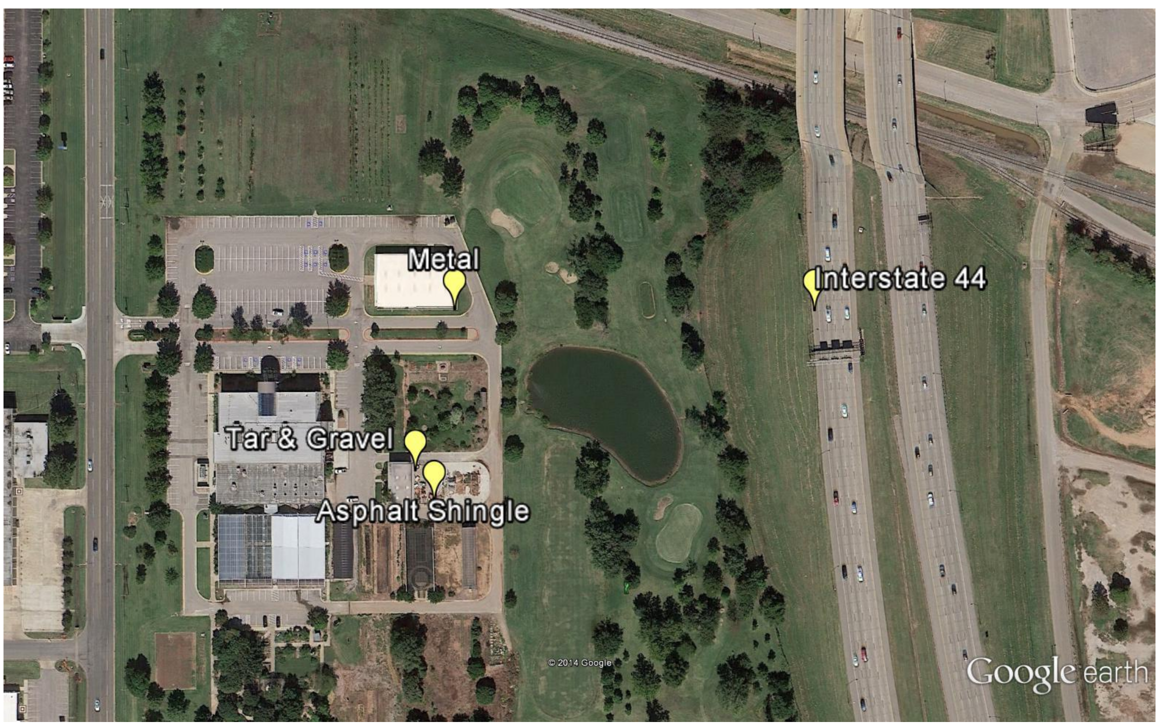

Figure 2-3. Locations of the metal, tar and gravel, and asphalt single roofs used in the Oklahoma City field sampling study in relation to the major highway, Interstate 44, located next to the roofs.

A single downspout from both the tar and gravel and metal roofs were replaced and modified with a PVC pipe configuration in order to allow for continuous water quality readings and sampling. A smaller yet identical PVC downspout configuration was placed at the asphalt shingle roof. The downspouts were designed to contain water in order to (1) store water in-between storm events to keep a water-quality sonde wet and (2) allow for sampling of rooftop runoff.

Portable samplers (6712, Teledyne Isco, Lincoln, NE) were programmed to take sequential samples at irregular time intervals, with the majority collected during the beginning of the storm. A water-quality sonde (Hydrolab MS5; Hach®, Loveland, CO) was placed inside each downspout to take continuous measurements of conductivity, turbidity, and temperature of the roof runoff throughout a storm event. Teflon-lined tubing was used for the suction line and was inserted into the downspouts, just below the sondes. Prior to collecting each sample, the suction line was rinsed twice. If no water was detected after three attempts, the sampler moved on to the next programmed sample event. A total of twelve one-liter paired samples were programmed to be collected for each roof during a storm event over a 3.27 hour timeframe. The second sample of each pair was programmed to be immediately collected after the first sample (within one minute). Rain gauges (674; Teledyne Isco, Lincoln, NE) were used to record rainfall data at the sites. Initially, only one rain gauge was installed at asphalt shingle roof. As the study progressed, rain gauges were also installed at the metal and tar and gravel roofs.

In order to measure the volume of runoff from each storm event, runoff depths were recorded by a submerged probe containing an internal differential pressure transducer (720 Submerged Probe Flow Module (Teledyne Isco, Lincoln, NE)) in conjunction with a 90° contracted V-notch weir. The weir was installed at one end of a 150 x 92 x 30 cm constructed plywood box placed at the outlet of each downspout (Figure 2-4) following recommendations from the United States Department of the Interior Bureau of Reclamation (Dodge 2001). The probe was installed

92 cm upstream from the weir plate. The Cone equation was used to calculate the discharge over the weir:

$$Q = 2.49{h_1}^{2.48} \tag{2-1}$$

where Q is the discharge over the weir (ft^3/s) and h_1 is the head on the weir (ft). Once Q was calculated, the values were converted to metric units (m^3/s) for subsequent calculations. The head on the weir readings were provided by the probe, with the distance from the bottom of the V-notch weir to the bottom of the box (7.6 cm) subtracted from the measured readings. For level readings < 7.6 cm, the continuity equation was used to calculate the flow rate inside the weir box:

$$Q = VA \tag{2-2}$$

where V is the velocity in m/s and A is the weir box area, in m^2. V was determined by calculating the change in level readings and dividing by 60 seconds (the time increment recorded for each level reading). In order to get the final runoff volume over a one minute period, the flow rates calculated using Equations 2-1 and 2-2 were added together and then multiplied by 60 seconds.

Figure 2-4. Example of the modified downspout and sampling arrangement at the metal roof in Oklahoma City.

2.3.3.1 Oklahoma City Sample Collection

Prior to a storm event, the portable samplers were programmed and filled with 24 one-liter polypropylene bottles. The pump and discharge tubing in the samplers were replaced with clean tubing before each collection event. The teflon suction lines between the downspouts and the sampler were not replaced as they were considered part of the downspout. The weir boxes were drained and the downspouts were rinsed and filled with tap water via garden hoses located on site. All plastic bottles, bottle lids, and tubing used in the portable samplers were thoroughly cleaned prior to use with laboratory-grade soap, three acetone rinses, and three rinses with a 10% nitric acid solution followed by deionized water. The equipment was then allowed to air dry before use.

Two different methods were used to trigger the portable samplers to begin sampling. Initially, the submerged probes were programmed to trigger the samplers. When this proved ineffective, the rain gauges were used to trigger the samplers. All samples were collected from the samplers within 12 hours of a storm event and immediately placed on ice. Rainfall activity was monitored from Stillwater using real-time data from the Oklahoma Mesonet station Oklahoma City West (station OKCW), which is located within 300 meters of all three roofs. The sampler and sonde data were downloaded onto laptops after all samples were placed on ice. Samples were brought back to Stillwater where they were immediately split into smaller sample bottles so that the samples could be sent to various labs for water-quality testing. Flowlink® 5.1 (Teledyne Isco, Lincoln, NE) was used to determine the six paired samples chosen from each roof based on when the samples were taken during the storm event.

2.3.4 Water-Quality Testing

2.3.4.1 Inorganics and Bacteria

As harvested rainwater can be used for irrigational purposes or watering lawns, the water quality of the samples were compared to Oklahoma irrigation water quality guidelines. Zhang

(2013) identified six classes for irrigation water quality in Oklahoma: excellent, good, fair, poor, very poor, and unsuitable. Descriptions of these six classes are given in Table 2-3.

Table 2-3. Oklahoma irrigation water classes based on soluble salt content and sodium percentage observed in irrigation water (Zhang 2013).

Irrigation Water Quality Class	Description
Class 1: Excellent	Total soluble salt content and sodium percentage are low enough to not cause problems with use.
Class 2: Good	Suitable for use on most crops under most conditions.
Class 3: Fair	Can be used successfully for most crops if care taken to prevent accumulation of soluble salts in soil, including sodium.
Class 4: Poor	Use is restricted to well-drained permeable soils for production of salt tolerant crops.
Class 5: Very Poor	Use is restricted to irrigation of sandy, well-drained soils in areas of state that receive at least 762 mm of rainfall.
Class 6: Unsuitable	Not recommended for crop irrigation.

Classifications for irrigation water quality based on electrical conductivity (EC), percent sodium, and approximate sodium-adsorption ratio (SAR) are shown in Figure 2-5. The SAR is based on concentrations of sodium (Na), calcium (Ca), and magnesium (Mg).

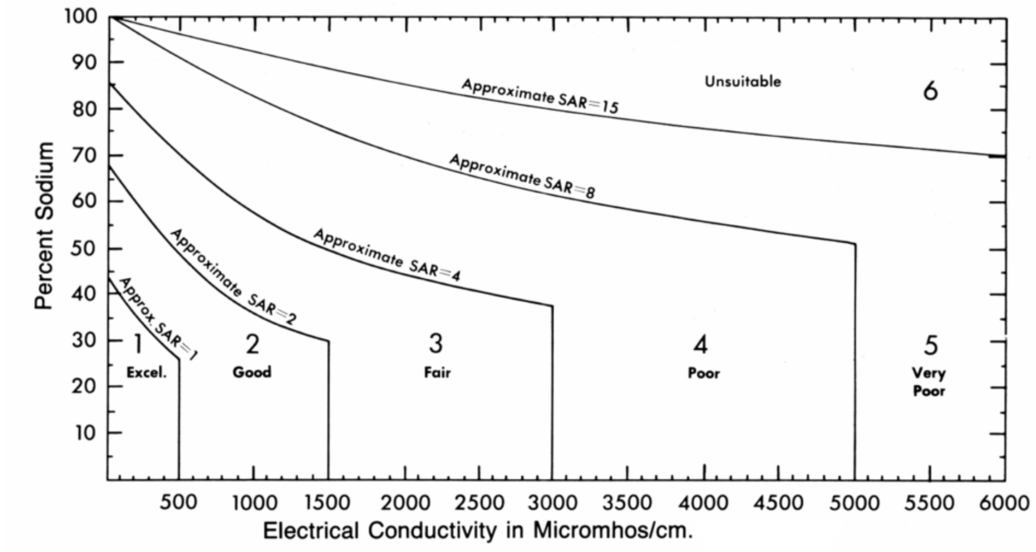

Figure 2-5. Diagram for classifying irrigation water in Oklahoma (Zhang 2013).

Boron (B), which is found in water as boric acid, can have toxic effects on plants at very low concentrations (Zhang 2013). Table 2-4 lists classifications for irrigation water quality based on B concentrations and crop tolerance. Examples of sensitive, semi-tolerant, and tolerant plants are listed in Table 2-5.

Table 2-4. Classification of irrigated water based on boron concentration (ppm) in relation to plant tolerance (Zhang 2013).

Classification	Sensitive Plants	Semi-Tolerant Plants	Tolerant Plants
Excellent	<0.3	<0.6	<1.0
Good	0.4-0.6	0.7-1.3	1.0-2.0
Fair	0.7-1.0	1.4-2.0	2.1-3.0
Poor	1.1-1.3	2.1-2.5	3.1-3.8
Unsuitable	>1.3	>2.5	>3.8

Table 2-5. Examples of plants and plant tolerance to boron concentrations in water (Zhang 2013).

Sensitive	Semi-Tolerant	Tolerant
Pecan	Sunflower	Sugar beet
Black Walnut	Cotton	Garden beet
Navy Bean	Radish	Alfalfa
Pear	Field Pea	Onion
Apple	Barley	Turnip
Peach	Wheat	Cabbage

Corn	Lettuce
Milo	Carrot
Oats	
Pumpkin	
Sweet Potato	

All samples were analyzed for pH, EC, nitrate-nitrogen (NO_3-N), boron (B), SAR and for dissolved iron (Fe), copper (Cu), zinc (Zn), and manganese (Mn) by the OSU Soil, Water, and Forage Analytical Laboratory (Stillwater, OK). Water samples were filtered through Fisher P-4 paper filters by lab personnel when visible sediment was observed in the samples. Samples were analyzed for pH and EC using a pH meter and a combination electrode and EC meter with dipping probe following Method 4500-H^+ and Method 2510, respectively (APHA et al. 2005). Sample analyses on Na, Ca, Mg, B, Fe, Cu, Zn, and Mn concentrations were conducted using inductively couple plasma (ICP) emission spectroscopy following Standard Methods 3120 (APHA et al. 2005). NO_3-N concentrations were analyzed following Standard Method 4500-$NO3^-$-I (APHA et al. 2005).

Samples were also analyzed for total suspended solid (TSS) concentrations following EPA Method 160.2. The 64 mm/hr simulation did not have samples analyzed for TSS due to laboratory issues. A portable turbidimeter (2100Q, Hach®, Loveland, CO), was used to measure turbidity readings of all samples following EPA Method 180.1. The samples were inverted three times in the original sample bottle before being poured into a turbidimeter glass sample cell. A total of five readings were taken for each sample. In-between each reading, the sample cell was removed and inverted three times to ensure that the sample was well-mixed for each of the five readings. The median value of the five readings was used for the final turbidity measurement for each sample.

OKC samples were tested for the presence of total coliforms and *Escherichia coli* (*E. coli*) bacteria by Ward Laboratories (Kearney, NE), but only if samples could be delivered overnight within 48 hours of initial collection (Pope et al. 2003). No bacteria testing was performed on SIM samples. Samples sent for bacteria testing were transferred from the field collection bottles to sterilized 100 mL bottles containing sodium thiosulfate and shipped in coolers containing ice and blue-ice packs using a next-day air service. Bacteria samples were processed immediately upon arrival at the testing laboratory using the Colilert Quanti-Tray®/2000 (IDEXX, Westbrook, Maine) Most Probable Number (MPN) method. A summary of methods used for water sample analysis are listed in Table 2-6.

2.3.4.2 Organic Contaminants of Concern

Samples were analyzed for the presence of seventeen PAHs (Σ17PAHs): naphthalene, 2-methyl naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene, and benzo(g,h,i)perylene, phosphorus flame retardants tris(2-chloroethyl) phosphate (TCEP), tris(1,3-dichloro-2-propyl) phosphate (TDCPP), and pyrethroid insecticides bifenthrin, cypermethrin, and lambda-cyhalothrin using solid-phase extraction (SPE) coupled with gas chromatography-mass spectrometry following EPA Method 525.3.

Table 2-6. Methods used for analyzing water samples.

Parameter	**Method**
pH	Standard Method 4500-H^+
Electrical conductivity (EC)	Standard Method 2510
B, Na, Ca, Mg, Fe, Cu, Zn, Mn	Standard Method 3120
NO_3-N	Standard Method 4500-$NO3^-$-I
Total suspended solids (TSS)	EPA Method 160.2
Turbidity	EPA Method 180.1
Total coliforms and *Escherichia coli*	Colilert (Quanti-Tray®/2000) Most Probable Number (MPN)
Polycyclic aromatic hydrocarbons, phosphorus flame retardants, and pyrethroid insecticides	EPA Method 525.3

BAKERBOND™ Octadecyl (C_{18}) (Avantor™, Center Valley, PA) 6 mL, 1000 mg SPE columns were used to extract the organic compounds of interest from a one-liter water sample. The water samples had 50 – 100 µg/L of p-Terphenyl added as a surrogate. Columns were conditioned using (in order) 5 mL of ethyl acetate, 5 mL of methanol, and 5 mL of deionized water (DI) while placed onto a vacuum manifold column processor. After the DI rinse, the columns were again filled with DI water. Teflon tubing was used to draw the water sample through the column with the aid of a vacuum pump attached to the vacuum manifold (Figure 2-6). One end of the tubing was placed inside the water sample with the opposite end inserted through a stopper approximately one inch; the stopper was then pressed into the top of the column to create a seal. The column's stopcock valve was opened to allow some of the DI water to draw through prior to placing the stopper.

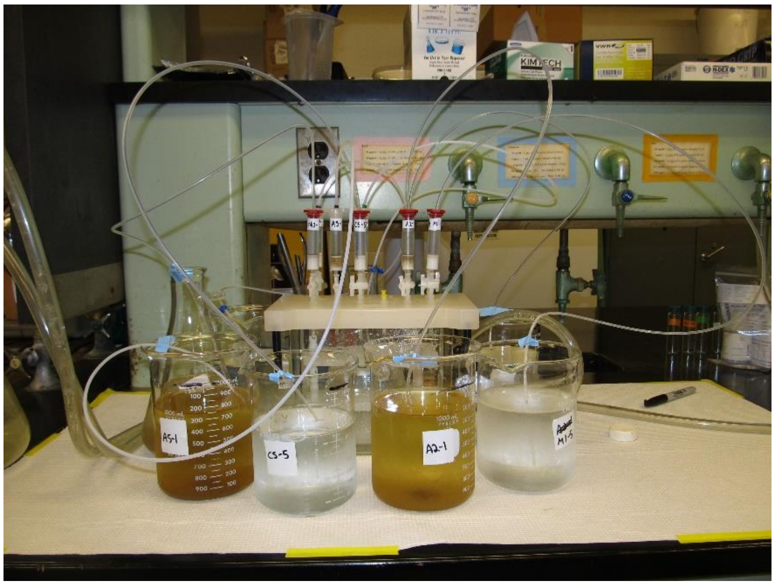

Figure 2-6. Extracting organic compounds from one-liter water samples using solid-phase extraction.

If the column became plugged due to particulates in the water samples, it was replaced with a new, conditioned column. The flow rate of the vacuum was 5 to 10 mL/min. Upon completion of this step, the columns were removed from the vacuum manifold and stored at -30°C until they were ready for elution. The bottles or glassware containing the original water samples and the tubing were rinsed with ethyl acetate and the rinse was transferred to glass vials to be later combined with the eluate.

Prior to elution, the columns were thawed (if required) and placed in plastic centrifuge tubes with conical bottoms and centrifuged for 5 minutes at 3000 rpm to remove any water. The columns were eluted using 9 mL of ethyl acetate into test tubes. The eluate was pipetted from the test tubes to its corresponding rinse vial. The test tubes were rinsed with ethyl acetate and the rinse was also pipetted to the same corresponding vial. Approximately 1 g of anhydrous sodium sulfate were added to the final eluate to absorb any water. The final eluate was frozen until the evaporation could occur.

After elution, the eluate was pipetted to 9 mL glass vials with conical interior bottoms. The vials were placed into a modular heating block in a dry block heater set at 45°C to assist with evaporation. A stream of nitrogen gas was directed onto the eluate until all of a sample's eluate was evaporated to 1 mL. The vials containing the eluate were rinsed with ethyl acetate and the rinse was combined and evaporated with the eluate. The final 1 mL of eluate was pipetted to a 2mL amber vial. The vials were frozen until analysis on an Agilent 6850 gas chromatograph coupled to an Agilent 5975C inert XL EI/CI MSD mass spectrometer with an Agilent 6850 series autosampler (Agilent, Palo Alto, CA).

The first sample from each OKC sample pair was analyzed for the PAHs, PFRs, and pyrethroid insecticides. The second of each paired sample was well mixed and split for analysis for the remaining water-quality analyses. Rainfall simulation samples were well mixed and split into three additional bottles for water-quality analysis while the remaining sample was reserved for the organics testing.

Detections of PAHs and pyrethroid insecticides were compared to Health-Based Screening Levels (HBSLs) to determine if runoff concentrations would be of potential concern for human health. The HBSLs were developed by the United States Geological Survey (USGS) in collaboration with the U.S. Environmental Protection Agency (USEPA), New Jersey Department of Environmental Protection, and Oregon Health and Science University in order to supplement existing Federal drinking-water standards and guidelines (Toccalino et al. 2012). HBSLs are calculated using three standard USEPA Office of Water equations used to establish drinking-water guideline values based on Lifetime Health Advisory and Cancer Risk Concentration values and the latest, USEPA peer-reviewed, publicly available human-health toxicity information (Toccalino et al. 2012). The HBSL dataset only contains calculations for contaminants that do not have USEPA Maximum Contaminant Levels (MCLs).

2.3.5 Quality Control and Method Development

Field replicates were performed for quality control and quality assurance purposes. Replicates were taken at ten percent of the 64 mm/hr simulation samples for pH, EC, NO_3-N, SAR, B, Fe, Cu, Zn, and Mn analysis and at ten percent of the 38 mm/hr and 28 mm/hr simulations for turbidity and TSS samples. Replicates on pH, EC, NO_3-N, SAR, B, Fe, Cu, Zn, Mn, turbidity, TSS, and bacteria samples were taken at approximately 11-20% of all OKC samples (n = 162); of the 84 samples used for data analysis (n = 41 for bacteria), there were 10 replicates on pH, EC, NO_3-N, SAR, B, Fe, Cu, Zn, Mn, and TSS, 9 turbidity replicates, and 3 bacteria replicates.

No replicates were performed on samples for PAHs, PFRs, or pyrethroid insecticides due to limitations with sample volumes required for the SPE process. Instead, lab matrix spikes were performed on three sets of duplicates from the last sample of three SIM samples (A4-6, C6-6, M4-6), representing each roofing material from the August simulation. A total of 12 field blanks were taken from the SIM site. Three field blanks were taken at OKC.

2.3.6 Statistical Analysis

Two-sample t-tests ($\alpha = 0.05$) were used to compare turbidity and TSS results from the NS and EW SIM samples to one another in order to determine if roof orientation in relation to the prevailing wind direction had a significant impact on rooftop runoff quality. Samples from each NS roof were compared to corresponding EW samples from the same roofing material for each simulation intensity. Both groups had a sample size of n = 3 for each two-sample t-test performed (de Winter 2013). When comparing TSS, samples with detections below the reporting limit were replaced with half the reporting limit, i.e. 0.5 mg/L.

Matrices were created based on Spearman's Rho correlations ($\alpha = 0.05$) to see if any trends existed between the water-quality parameters/constituents and roof type (SIM and OKC samples) and simulation intensity (SIM samples). Ranked data were used in order to account for non-detects (Helsel 2012). Spearman's Rho (r_s) values were computed in Minitab and critical r_s values were calculated based on Student's t critical values ($\alpha = 0.05$) for a given sample size using (Zar 1972),

$$\boldsymbol{t = r_s\sqrt{\frac{n-2}{1-r_s^2}}} \tag{2-3}$$

where t is the Student's t critical value, r_s is the Spearman's rho value, and n is the sample size.

The majority of samples were highly left-censored; therefore data were summarized following nonparametric methods after censoring at the highest reporting limit (Helsel 2012). Binary methods were used to summarize the number of samples greater than the reporting limit and the frequency of detections. Maximum values were also reported. Parameters not requiring censoring were pH, EC, and turbidity for both SIM and OKC samples and TSS for OKC samples.

Tukey-Kramer analysis ($\alpha = 0.05$) was used for statistical comparisons on SIM samples (based on intensity, roof type, and sample number) and OKC samples (based on roof type and runoff depth with ADP as a covariate) using the ANOVA-GLM in Minitab (Minitab Inc., State College, PA). For censored data, a Kruskal-Wallis test ($\alpha = 0.05$) was first performed to determine if significant differences existed. If there was a significant difference ($p < 0.05$), pairwise comparisons were performed using Tukey-Kramer after ranking the censored data.

2.4 Results and Discussion

2.4.1 Quality Control and Method Development

The RO system used to filter the simulation water was discovered to have been installed incorrectly, resulting in some SIM field blanks containing detectable concentrations of EC, NO_3-N, SAR, B, Fe, Cu, Zn, Mn, and TSS; background concentrations for all except EC were subtracted from sample concentrations. Naphthalene was the only PAH detected in five of the SIM field blanks (35-79 ng/L); there were no other detections of the organic compounds of interest in the blanks. Three lab blanks were performed during the OKC SPE sample processing; there was one detection of naphthalene (33 ng/L) in one of the three lab blanks. The OKC field blanks had no detections of the organic compounds.

The average recovery of the surrogate p-Terphenyl was 86.3% (±22) for SIM samples, 89.7% (±19.5) for the OKC samples, and 83.8% (±8) for the six laboratory spikes. Average lab matrix spike recoveries ranged between 61.5% (±21.3) and 96.3% (±25.6) for the PAH compounds and between 89.3% (±33) and 109.8% (±17.8) for the pyrethroid insecticides. There were no detections of TCEP or TDCPP in the samples, therefore there were no recoveries in the matrix study. Detailed recoveries on lab spikes, and matrix spikes, and replicate results can be found in Appendix A for simulation samples and Appendix B for OKC samples.

2.4.2 Runoff Volumes

2.4.2.1 Simulation Events

Each roof produced different runoff volumes, which was dependent on both the simulation intensity and roofing materials. Table 2-7 provides a summary of the average total runoff volumes along with the average harvesting efficiency from each rainfall simulation based on roofing material. Theoretical efficiencies are based on a review and calculations by Farreny et al. (2011).

Table 2-7. Summary of the sample volumes from the three simulated rainfall events for the asphalt shingle, metal, and clay tile roofs.

Roofing Material	Simulation Intensity (mm/hr)	Theoretical Harvesting Efficiency (Farreny et al. 2011)	Average Harvesting Efficiency ± Standard Deviation	Average Total Runoff Volume Collected from Roofs (L) ± Standard Deviation
Asphalt Shingle	64	0.90	0.80 ± 0.11	30.6 ± 4.14
Metal		0.92	0.87 ±0.08	33.1 ± 3.13
Clay Tile		0.84	0.68 ± 0.06	25.8 ± 2.30
Asphalt Shingle	38	0.90	0.75 ± 0.19	23.8 ± 6.15

Metal		0.92	0.77 ± 0.17	24.5 ± 5.49
Clay Tile		0.84	0.66 ± 0.08	21.0 ± 2.48
Asphalt Shingle	28	0.90	0.79 ± 0.05	18.4 ± 1.05
Metal		0.92	0.81 ± 0.08*	18.8 ± 1.92*
Clay Tile		0.84	0.77 ± 0.09	18.1 ± 1.99

* Average for 5 roofs; one roof did not have a composite sample due to field issues.

2.4.2.2 Oklahoma City Field Sampling

Samples were collected from 11 storm events between April and July 2012. Table 2-8 provides the dates, antecedent dry periods (ADP), roofs sampled, catchment efficiency, and rainfall measurements from each site. Farreny et al. (2011) calculated a global runoff coefficient based on runoff results for a clay tile, metal, plastic, and flat gravel roof from 25, 22, 23, and 22 monitored events, respectively. The total annual runoff volume from each roof was then divided by the annual rainfall to produce the global runoff coefficient (Farreny et al. 2011). Global runoff coefficients produced for metal and flat gravel roofs were 0.92 ±0.00, and 0.62 ±0.04, respectively, while asphalt shingles were estimated to have a runoff coefficient of 0.9 (Farreny et al. 2011).

Roof harvesting efficiencies observed in the OKC study were much lower than those suggested by Farreny et al. (2011) for all three roofs. The lower harvesting efficiencies for the metal roof were observed when the measured rainfall amounts at the metal roof were low, i.e. 6.60 and 2.29 mm (S8 and S11, Table 2-8). The metal roof also had lower harvesting efficiencies during storm events S2, S4, and S5. There was no rain gauge installed at the metal roof for these storm events, but the rainfall amounts measured at the asphalt shingle roof were 5.08, 9.40, and 6.10 mm for S2, S4, and S5, respectively. There is a possibility that the metal roof did not receive as much rainfall as the asphalt shingle roof during those storm events, which would explain why the harvesting efficiencies were so low. Even though the metal roof is within 100 m of the asphalt shingle and tar and gravel roof, rainfall measurements from S8, when all three roofs had a rain gauge installed on site, show the potential for all three roofs to receive different amounts of rainfall during the same storm event. The asphalt shingle roof had a consistent harvesting efficiency throughout the study, ranging between 0.73 – 0.78. These observed efficiencies compared to the typical efficiency of 0.9 could be a result of the low slope of the roof; the asphalt shingle roof in the study had a slope of approximately 7°.

The tar and gravel roof had the poorest harvesting efficiency of all three roofs at the OKC site, with efficiencies as low as 0.04. Flat tar and gravel roofs have a higher initial abstraction due to the porosity provided by the gravel, allowing for a high water retention capacity and detention/abstraction values ranging between 2.5 to 7.5 mm (Farreny et al. 2011). These high initial abstraction values for tar and gravel roofs explain why extremely low harvesting efficiencies were observed in this study for this type of roof.

Table 2-8. Description of storm events sampled in 2012 from the metal, tar and gravel, and asphalt shingle roofs at the OKC site.

Date (2012)	Storm Event	ADP (days)	Measured Rainfall at Each Roof (mm)			Measured Roof-Runoff Volumes (L)			Roof Harvesting Efficiency		
			Metal	Tar & Gravel	Asphalt Shingle	Metal	Tar & Gravel	Asphalt Shingle	Metal	Tar & Gravel	Asphalt Shingle
3 April	S1	11	12.4*	-	-	870	-	-	0.80	-	-
11 April	S2	7	5.08*	5.08*	5.08	93	44	37	0.21	0.09	0.78
13 April	S3	1	21.1*	21.1*	21.1	1291	1058	153	0.70	0.55	0.78
19 April	S4	3	9.40*	9.40*	9.40	339	97	64	0.41	0.11	0.73
28 April	S5	8	6.10*	6.35	-	189	125	-	0.35	0.22	-
11 May	S6	9	-	-	4.06	-	-	29	-	-	0.77
20 May	S7	6	5.84	6.86	-	359	112	-	0.70	0.18	-
29 May	S8	6	6.60	15.5	20.8	347	237	144	0.60	0.17	0.74
6 June	S9	2	9.65	9.91	8.89	764	34	64	0.90	0.04	0.77
15 June	S10	7	32.0	34.5	-	2285	267	-	0.81	0.08	-
9 July	S11	17	2.29	-	2.79	70	-	20	0.35	-	0.77

Note: *Used rainfall measurements from the rain gauge placed at the asphalt shingle roof due to no rain gauge being installed at the roof for the given storm event. ADP = Antecedent dry period. The harvesting efficiency is based on the measured rainfall, roof area, and measured runoff from each storm event. A dash (-) indications no samples were collected.

2.4.3 Water-Quality Summaries

2.4.3.1 Simulation Events

The pH was significantly different for all three intensities (Table 2-9). The pH of runoff from asphalt shingle roofs were significantly different from metal and clay tile roofs (Table 2-10). The first samples collected from the roofs (i.e. runoff depth 0 – 1.2 mm) were significantly different from subsequent samples (Table 2-11). The interquartile range and outliers for pH based on roof type and intensity are shown in Figure 2-7 while pH based on sample number and roof type for all simulations are shown in Figure 2-8. Background pH levels from the simulation water are indicated on Figures 2-7 and 2-8 by dashed lines. Descriptive statistics for the average pH, EC, and turbidity for each sample based on roof and simulation event are shown in Tables 2-12 to 2-14.

All three simulations had different background pH levels. The simulation water (background) pH levels were 7.20 (64 mm/hr), 7.15 (38 mm/hr), and 6.42 (28 mm/hr). It is hypothesized that the differences in pH may be due to the storage method of the simulation water. The tank used to store the water for the simulations contained some residue on the walls. Attempts were made to power wash the residue from the tank walls prior to the study, however, some residue was still observed in the simulation field blanks. The tank was power-washed a second time after the 38 mm/hr simulation, which may explain why the pH was much lower on the 28 mm/hr simulation.

Several studies have observed that roof runoff tends to have higher pH levels compared to ambient rainfall (Nicholson et al. 2009, Mendez et al. 2011, Farreny et al. 2011, Ltd et al. 2004, Göbel et al. 2007, Meera and Ahammed 2006, Ward et al. 2013, Chang et al. 2004). The pH from all runoff samples ranged between 6.24 and 8.20 (min and max). Neutralization of the simulation water was most noticeable from the 28 mm/hr simulation as the water was at a much lower pH level (6.42) initially compared to the average values observed in the initial runoff samples (6.96 – 7.32 pH).

Table 2-9. pH and statistical comparisons between rainfall simulation intensities. Different letters in the ANOVA column indicate there was a significant difference between samples.

Intensity (mm/hr)	pH Mean	ANOVA Results (α = 0.05)
64	6.97	A
38	7.08	B
28	6.73	C

Table 2-10. pH and statistical comparisons between roof types from the simulation events. Different letters in the ANOVA column indicate there was a significant difference between samples.

Roof Type	pH Mean	ANOVA Results (α = 0.05)
Asphalt Shingle	6.88	A
Metal	6.92	B
Clay Tile	6.90	B

Table 2-11. pH and statistical comparisons between runoff depths from the rainfall simulations. Different letters in the ANOVA column indicate there was a significant difference between samples.

Runoff Depth (mm)	pH Mean	ANOVA Results (α = 0.05)
0-1.2	7.02	A
1.2-2.4	6.99	B
2.4-3.6	6.91	BC
3.6-4.8	6.86	C
4.8-6.0	6.85	C
6.0-27	6.80	C

Table 2-12. Descriptive statistics on the pH, conductivity (EC), and turbidity of samples collected from the asphalt shingle roofs during the three simulated rainfall events.

Simulation Intensity	Sample Number	Runoff Depths (mm)	Mean pH	±Standard Deviation	Mean EC (µS/cm)	±Standard Deviation	Mean Turbidity (NTU)	±Standard Deviation
64 mm/hr	1	0-1.2	6.52	0.05	191	9.2	25.2	37.2
	2	1.2-2.4	6.83	0.06	58	6.1	6.08	5.18
	3	2.4-3.6	6.94	0.09	47	3.5	2.64	1.02
	4	3.6-4.8	6.92	0.08	42	1.7	2.31	1.45
	5	4.8-6.0	6.91	0.11	39	1.4	1.72	0.75
	6	6.0-21	6.94	0.07	36	1.6	0.89	0.34
38 mm/hr	1	0-1.2	7.10	0.14	60	16.7	10.7	5.07
	2	1.2-2.4	7.06	0.11	32	1.9	2.97	1.26
	3	2.4-3.6	7.06	0.07	28	1.2	1.87	0.91
	4	3.6-4.8	7.03	0.10	35	21.1	1.60	0.41
	5	4.8-6.0	7.04	0.09	26	0.9	1.48	0.47
	6	6.0-19	6.78	0.34	25	0.8	1.24	0.46
28 mm/hr	1	0-1.2	6.96	0.09	62	9.3	5.48	2.48
	2	1.2-2.4	6.93	0.06	21	4.5	1.63	0.67
	3	2.4-3.6	6.82	0.06	17	4.2	1.15	0.36
	4	3.6-4.8	6.83	0.10	16	3.9	0.75	0.29
	5	4.8-6.0	6.83	0.11	16	5.4	0.98	0.57
	6	6.0-12	6.78	0.15	16	6.3	0.83	0.28

Note: Sample number six has different runoff depths for each simulation event due to the differences in simulation intensities.

Table 2-13. Descriptive statistics on the pH, conductivity (EC), and turbidity of samples collected from the metal roofs during the three simulated rainfall events.

Simulation Intensity	Sample Number	Runoff Depths (mm)	Mean pH	±Standard Deviation	Mean EC (µS/cm)	±Standard Deviation	Mean Turbidity (NTU)	±Standard Deviation
64 mm/hr	1	0-1.2	7.06	0.11	102	5.6	16.3	16.0
	2	1.2-2.4	7.12	0.12	42	2.2	2.42	1.16
	3	2.4-3.6	7.08	0.10	37	1.2	1.95	0.94
	4	3.6-4.8	7.07	0.13	36	1.1	0.84	0.26
	5	4.8-6.0	7.10	0.11	35	0.9	1.10	0.23
	6	6.0-22	7.17	0.13	35	0.6	0.38	0.06
38 mm/hr	1	0-1.2	7.42	0.22	46	4.7	17.5	12.4
	2	1.2-2.4	7.23	0.10	27	1.5	2.31	1.75
	3	2.4-3.6	7.11	0.06	24	1.4	2.47	2.69
	4	3.6-4.8	7.06	0.09	23	0.6	1.68	0.84
	5	4.8-6.0	7.06	0.07	23	0.8	1.14	0.73
	6	6.0-19	7.05	0.04	23	0.9	1.11	0.62
28 mm/hr	1	0-1.2	7.32	0.40	24	3.2	0.96	0.21
	2	1.2-2.4	6.84	0.18	13	3.8	0.36	0.06
	3	2.4-3.6	6.68	0.11	11	3.9	0.34	0.11
	4	3.6-4.8	6.59	0.12	11	4.9	0.32	0.03
	5	4.8-6.0	6.55	0.14	10	4.0	0.27	0.05
	6	6.0-13	6.52	0.18	10	4.2	0.26	0.08

Note: Sample number six has different runoff depths for each simulation event due to the differences in simulation intensities.

Table 2-14. Descriptive statistics on the pH, conductivity (EC), and turbidity of samples collected from the clay tile roofs during the three simulated rainfall events.

Simulation Intensity	Sample Number	Runoff Depths (mm)	Mean pH	±Standard Deviation	Mean EC (µS/cm)	±Standard Deviation	Mean Turbidity (NTU)	±Standard Deviation
64 mm/hr	1	0-1.2	7.03	0.12	97	7.8	24.5	23.3
	2	1.2-2.4	7.03	0.16	42	2.6	1.39	1.09
	3	2.4-3.6	7.10	0.14	37	2.3	1.15	0.29
	4	3.6-4.8	7.08	0.15	37	1.9	0.81	0.69
	5	4.8-6.0	7.11	0.13	36	2.0	0.86	0.61
	6	6.0-17	7.12	0.12	36	1.6	0.47	0.14
38 mm/hr	1	0-1.2	7.37	0.16	59	4.7	15.0	11.3
	2	1.2-2.4	7.13	0.09	32	2.5	2.38	1.08
	3	2.4-3.6	7.08	0.05	27	2.4	2.11	0.58
	4	3.6-4.8	7.07	0.04	25	1.5	1.26	0.33
	5	4.8-6.0	7.06	0.02	25	2.2	1.25	0.47
	6	6.0-15	7.05	0.06	24	1.7	1.12	0.59
28 mm/hr	1	0-1.2	7.26	0.12	33	5.7	1.70	0.48
	2	1.2-2.4	6.88	0.07	15	3.1	0.56	0.19
	3	2.4-3.6	6.68	0.11	12	3.1	0.39	0.08
	4	3.6-4.8	6.58	0.12	11	3.5	0.34	0.08
	5	4.8-6.0	6.53	0.09	11	3.1	0.34	0.04
	6	6.0-13	6.46	0.19	10	3.4	0.36	0.10

Note: Sample number six has different runoff depths for each simulation event due to the differences in simulation intensities.

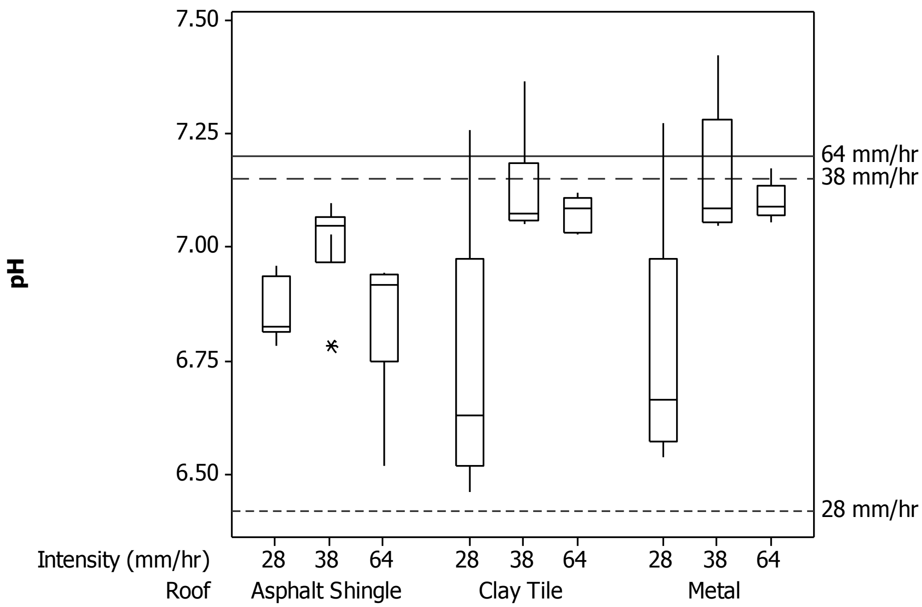

Figure 2-7. pH results from the rainfall simulation events based on intensity and roof type for all samples. The dashed lines represent the background pH levels observed in the simulation water.

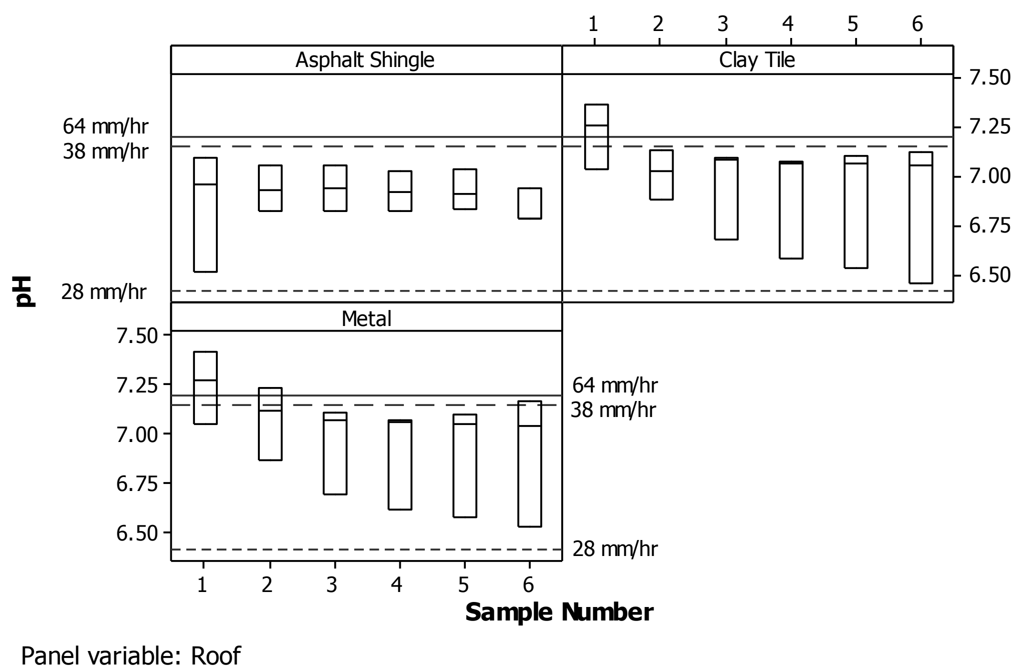

Figure 2-8. pH results from the rainfall simulation events based on sample number and roof type for all intensities. The dashed lines represent the background pH levels observed in the simulation water.

Mendez et al. (2011) observed the average EC of ambient rainfall to be 34 µS/cm and the EC of the first flush to be significantly higher than the rainwater harvested after first flush for shingle, metal and cool pilot-scale roofs. Tables 2-15 and 2-16 show comparisons in the mean conductivity measurements based on simulation intensity and roof type, along with whether or not the categories were significantly different from one another. Samples representing runoff depths 0 – 1.2 mm and 1.2 – 2.3 mm were significantly different from subsequent samples, indicating a first flush occurrence (Table 2-17). The EC was significantly different for all intensities and roof types. The EC concentrations never exceeded limits that would be detrimental for irrigation water; generally, there are no limitations when the EC is <750 µS/cm (Bauder et al. 2011).

Table 2-15. Conductivity and statistical comparisons between rainfall simulation intensities. Different letters in the ANOVA column indicate there was a significant difference between samples.

Intensity (mm/hr)	Conductivity Mean µS/cm	ANOVA Results (α = 0.05)
64	55	A
38	31	B
28	18	C

Table 2-16. Conductivity and statistical comparisons between roof types from the simulation events. Different letters in the ANOVA column indicate there was a significant difference between samples.

Roof Type	Conductivity Mean µS/cm	ANOVA Results (α = 0.05)
Asphalt Shingle	43	A
Metal	30	B
Clay Tile	32	C

Table 2-17. Conductivity and statistical comparisons between runoff depths from the rainfall simulations. Different letters in the ANOVA column indicate there was a significant difference between samples.

Runoff Depth (mm)	Conductivity Mean µS/cm	ANOVA Results (α = 0.05)
0-1.2	75	A
1.2-2.4	31	B
2.4-3.6	27	C
3.6-4.8	26	C
4.8-6.0	25	C
6.0-27	24	C

The interquartile range and outliers for EC based on roof type and intensity are shown in Figure 2-9 while EC based on sample number and roof type for all simulations are shown in Figure 2-10. The EC from each roof were averaged by sample number; background EC concentrations from the simulation water are indicated by dashed lines on Figures 2-9 and 2-10.

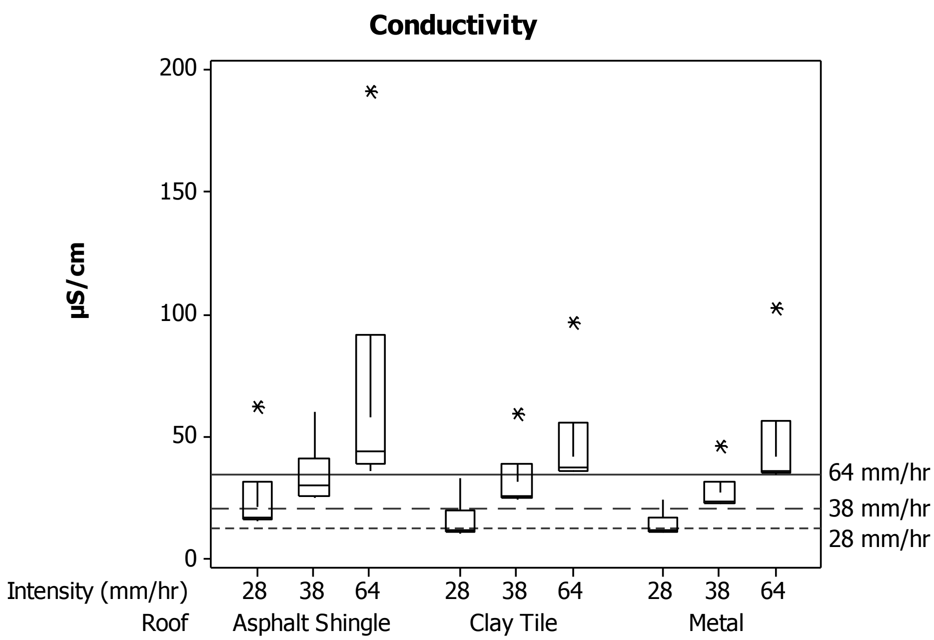

Figure 2-9. Conductivity results from the rainfall simulation events based on intensity and roof type for all samples. The dashed lines represent the background conductivity levels observed in the simulation water.

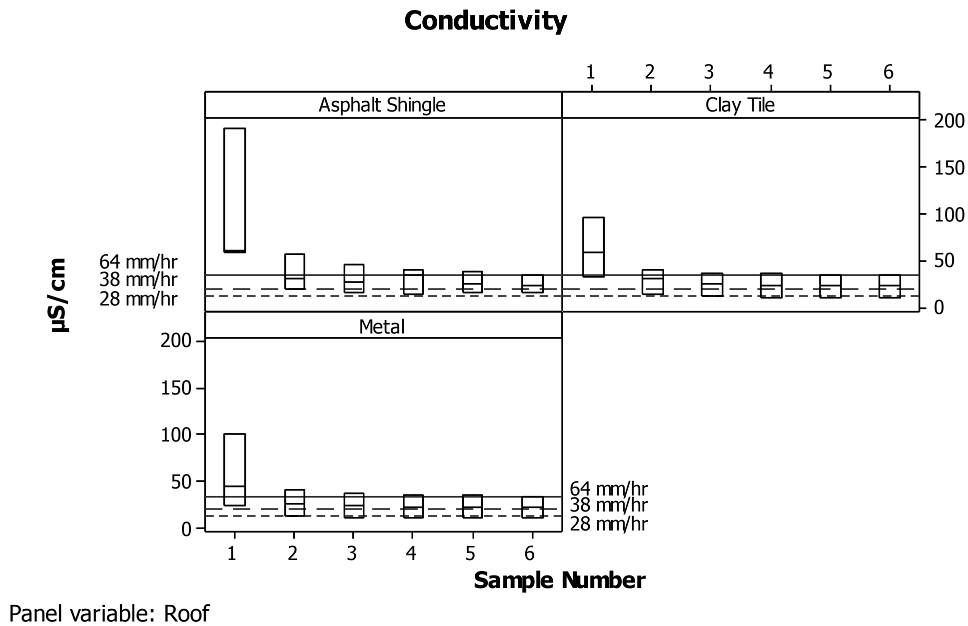

Figure 2-10. Conductivity results from the rainfall simulation events based on sample number and roof type for all intensities. The dashed lines represent the background conductivity levels observed in the simulation water.

The interquartile range and outliers for turbidity based on roof type and intensity are shown in Figure 2-11 while turbidity based on sample number and roof type for all simulations are shown in Figure 2-12. The turbidity readings from each roof were averaged by runoff depth. The two higher intensity simulations were significantly different from the lowest intensity simulation (Table 2-18). There were no significant differences in turbidity between roof types (Table 2-19). Samples representing the first 1.2 mm of runoff were significantly different from subsequent samples, indicating a first-flush effect (Table 2-20). Egodawatta et al. (2009), in a study on build-up and wash-off process on roof surfaces, observed that the highest concentrations of particulate matter were measured during the initial period of a runoff event. This first flush effect was also observed in the SIM turbidity data.

Table 2-18. Turbidity and statistical comparisons between rainfall simulation intensities. Different letters in the ANOVA column indicate there was a significant difference between samples.

Intensity (mm/hr)	Turbidity Mean NTU	ANOVA Results (α = 0.05)
64	5.06	A
38	3.85	A
28	0.94	B

Table 2-19. Turbidity and statistical comparisons between roof types from the simulation events. Different letters in the ANOVA column indicate there was a significant difference between samples.

Roof Type	Turbidity Mean NTU	ANOVA Results (α = 0.05)
Asphalt Shingle	3.86	A
Metal	2.88	A
Clay Tile	3.11	A

Table 2-20. Turbidity and statistical comparisons between runoff depths from the rainfall simulations. Different letters in the ANOVA column indicate there was a significant difference between samples.

Runoff Depth (mm)	Turbidity Mean NTU	ANOVA Results (α = 0.05)
0-1.2	13	A
1.2-2.4	2.2	B
2.4-3.6	1.6	B
3.6-4.8	1.1	B
4.8-6.0	1.0	B
6.0-27	0.7	B

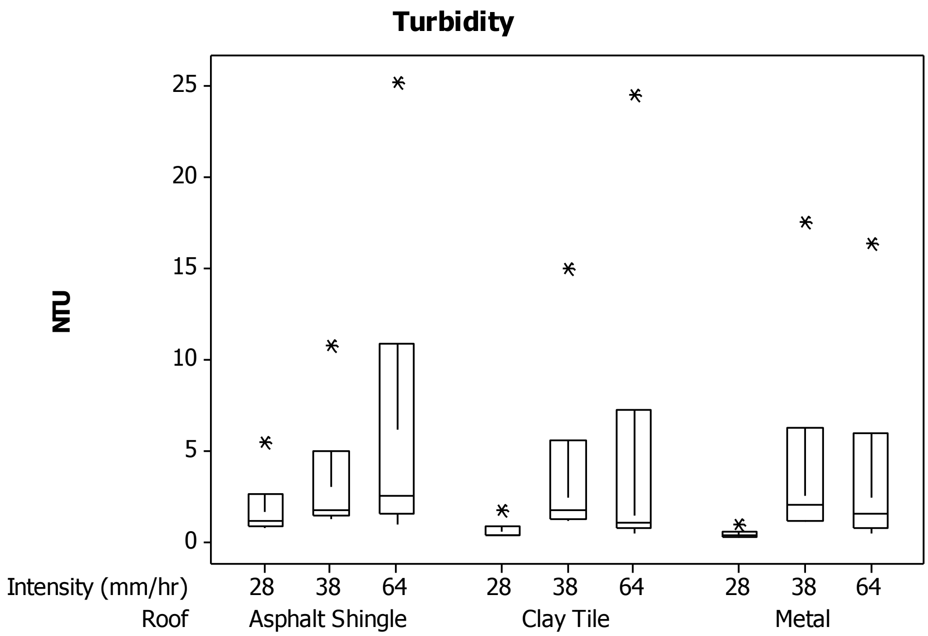

Figure 2-11. Turbidity results from the rainfall simulation events based on intensity and roof type for all samples.

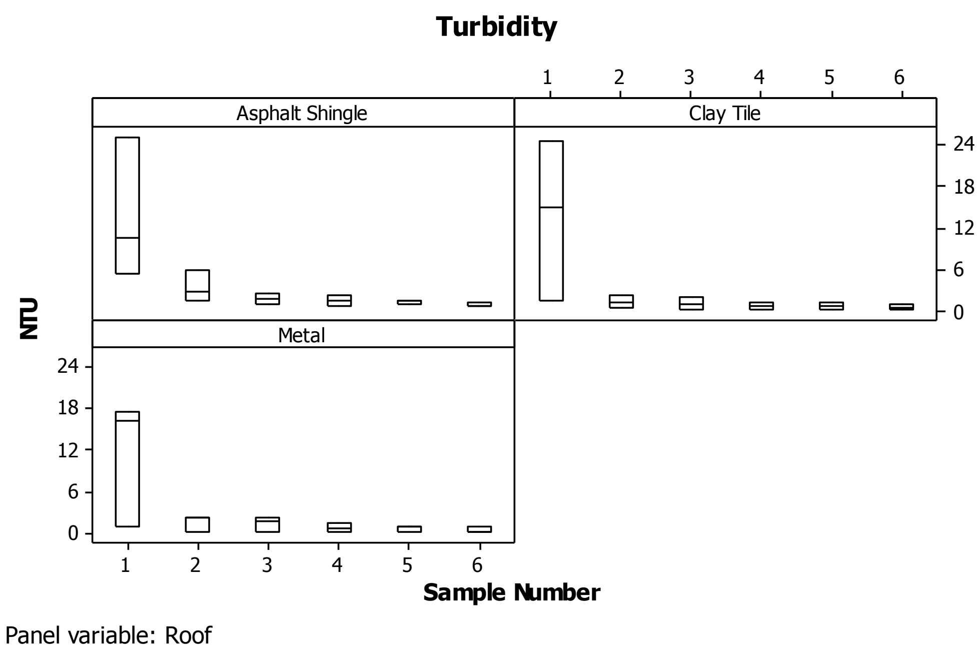

Figure 2-12. Turbidity results from the rainfall simulations based on sample number and roof type for all intensities.

Table 2-21 provides a summary of the Tukey-Kramer comparisons between the water quality parameters and constituents based on simulation intensity, roof type, and runoff depth in the form of an ANOVA table. Comparisons were not performed on B, Mn, bifenthrin cypermenthrin, or lambda-cyhalothrin due to either low frequency of detection or non-detection. Table 2-22 provides a summary of water-quality values measured for both organic and inorganic compounds in SIM samples. The metal roofs have one fewer final (sixth) sample due to one final sample bottle not being filled during the 28 mm/hr simulation. Only samples one, two, three, and six were analyzed for organic compounds. Samples were analyzed for TSS only for the 38 and 28 mm/hr simulations. The Σ17PAHs include all the PAHs the samples were analyzed for and it had a QL of >300 ng/L. The ΣCommonly Detected PAHs had a QL of >75 ng/L and include fluoranthene, pyrene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, and ideno(1,2,3-cd)pyrene. The ΣCarcinogenic PAHs had a QL of >70 ng/L and include benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene.

In the lighter-weight PAHs, fluoranthene had the highest frequency of detection in asphalt shingle runoff while naphthalene had the highest detection in metal and clay tile runoff. Fluoranthene was the next highest detected lighter-weight PAH in metal and clay tile runoff. Of the carcinogenic PAHs, Benzo(a)pyrene was detected at a higher frequency in runoff from asphalt shingle than both metal and clay tile roofs. Chrysene and ideno(1,2,3-cd)pyrene were the most commonly detected carcinogenic PAHs in asphalt shingle runoff; benzo(b)fluoranthene and ideno(1,2,3-cd)pyrene for metal runoff; and benzo(b)fluoranthene for clay tile runoff.

TDCPP was observed in greater frequency than TCEP with detections in runoff from all three roof types, with the highest concentration observed in the order of clay tile>asphalt shingle>metal. Bifenthrin was the only pesticide detected in all of the samples, with only one detection reported in an asphalt shingle sample.

Fe, Cu, and Mn were detected in higher frequencies in asphalt shingle runoff than metal and clay tile runoff. In a study by Nicholson et al. (2009), asphalt fiberglass shingles roofs had more copper in the runoff compared to galvanized metal or green roofs. Mendez et al. (2011) also observed similar results in comparing asphalt shingle roofs to metal, tile, cool, and green roofs and suggested that the shingle roof was a source of copper. The asphalt shingle roofs in the study by Mendez et al. (2011) also had higher concentrations of Fe compared to the other roofs. The metal roofs had the highest detection of Zn due to the metallic coating containing 40-48% of Zn. Boron was only detected in 6% of asphalt shingle samples. While asphalt shingle samples had the highest detection frequency of TSS, the metal roofs had the highest concentration.

Table 2-21. ANOVA summary for simulation events. Different letters within each category (intensity, roof, and runoff depth) indicate a significant difference was observed (α = 0.05).

Parameter	**Intensity (mm/hr)**			**Roof**			**Runoff Depth (mm)**					
	64	**38**	**28**	**Asphalt Shingle**	**Metal**	**Clay Tile**	**0-1.2**	**1.2-2.4**	**2.4-3.6**	**3.6-4.8**	**4.8-6.0**	**6.0-22**
Sample Size	**108**	**108**	**107**	**108**	**107**	**108**	**54**	**54**	**54**	**54**	**54**	**53**
pH	A	B	C	A	B	B	A	B	BC	C	C	C
EC	A	B	C	A	B	C	A	B	C	C	C	C
Turbidity	A	A	B	A	A	A	A	B	B	B	B	B
NO_3-N	A	B	C	A	B	A	A	B	BC	CD	CD	D
SAR	A	B	B	A	B	AB	A	A	B	B	B	C
Fe	A	B	B	A	B	AB	A	B	BC	C	C	C
Cu	A	B	B	A	B	B	A	B	BC	BC	C	C
Zn	A	B	C	A	B	C	A	AB	BC	CD	CD	D
Total Suspended Solids	-	A	B	A	B	B	A	B	C	CD	DE	E
Sample Size	**72**	**72**	**71**	**72**	**71**	**72**	**54**	**54**	**54**	**-**	**-**	**53**
∑17PAHs	A	B	A	A	A	A	A	B	B	-	-	B
∑Commonly Detected PAHs	A	B	C	A	B	B	A	B	B	-	-	B
∑Carcinogenic PAHs	A	B	C	A	B	B	A	B	C	-	-	C
Fluoranthene	A	B	C	A	B	B	A	B	C	-	-	C
Benzo(a)pyrene	A	B	B	A	B	B	A	B	C	-	-	C
TDCPP	A	B	C	A	A	A	A	A	A	-	-	B

No TSS data for 64 mm/hr intensity due to errors in processing samples. A total of six samples were collected from each roof per rainfall intensity. The first give samples were two liters in volume; the sixth sample ranged between six to 22 liters due to the varying sample volumes collected from each roof resulting from the different roofing materials and rainfall intensities. Samples collected at runoff depths 3.6-6.0 were not analyzed for the presence of polycyclic aromatic hydrocarbons (PAHs). TDCPP = tris(1,3-dichloro-2-propyl) phosphate. ∑17PAHs: naphthalene, 2-methyl naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene, and benzo(g,h,i)perylene; ΣCommonly Detected PAHs: fluoranthene, pyrene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, and ideno(1,2,3-cd)pyrene; ΣCarcinogenic PAHs: benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene.

Table 2-22. Water-quality summaries for samples collected from the simulated rainfall events that also had non-detects reported.

	RL	n Total	Asphalt Shingle n	Asphalt Shingle Freq. > RL	Asphalt Shingle Max Value	Asphalt Shingle 90th Percentile	Metal n	Metal Freq. > RL	Metal Max Value	Metal 90th Percentile	Clay Tile n	Clay Tile Freq. > RL	Clay Tile Max Value	Clay Tile 90th Percentile
Naphthalene	30 ng/L	215	72	44%	104	89	71	48%	112	77	72	61%	143	89
2-Methylnaphthalene	30 ng/L	215	72	3%	81	<30	71	6%	42	<30	72	3%	32	<30
Acenaphthylene	30 ng/L	215	72	0%	<30	<30	71	0%	<30	<30	72	0%	<30	<30
Acenaphthene	30 ng/L	215	72	3%	37	<30	71	0%	<30	<30	72	0%	<30	<30
Fluorene	30 ng/L	215	72	1%	55	<30	71	1%	31	<30	72	0%	<30	<30
Phenanthrene	30 ng/L	215	72	22%	86	55	71	20%	87	45	72	17%	90	38
Anthracene	15 ng/L	215	72	0%	<15	<15	71	0%	<15	<15	72	0%	<15	<15
Fluoranthene	15 ng/L	215	72	68%	140	111	71	37%	232	81	72	35%	217	94
Pyrene	10 ng/L	215	72	63%	121	82	71	34%	167	56	72	32%	151	63
Benz(a)anthracene	10 ng/L	215	72	26%	44	31	71	18%	67	30	72	15%	69	26
Chrysene	10 ng/L	215	72	53%	114	70	71	24%	192	43	72	22%	135	45
Benzo(b)fluoranthene	10 ng/L	215	72	51%	173	81	71	25%	146	73	72	28%	134	48
Benzo(k)fluoranthene	10 ng/L	215	72	39%	86	44	71	24%	116	45	72	22%	92	30
Benzo(a)pyrene	10 ng/L	215	72	40%	93	51	71	25%	118	33	72	25%	112	41
Indeno(1,2,3-cd)pyrene	10 ng/L	215	72	53%	117	68	71	25%	149	56	72	26%	137	48
Dibenz(a,h)anthracene	10 ng/L	215	72	4%	12	<10	71	4%	12	<10	72	3%	12	<10
Benzo(g,h,i)perylene	10 ng/L	215	72	33%	84	43	71	25%	86	45	72	25%	81	33
∑17PAHs	>300 ng/L	215	72	19%	1060	735	71	21%	1375	559	72	17%	1242	496
∑Commonly Detected PAHs	>75 ng/L	215	72	42%	816	513	71	24%	1056	399	72	22%	978	372
∑Probable Carcinogenic PAHs	>70 ng/L	215	72	36%	609	353	71	23%	716	322	72	22%	667	264
Tris(2-chloroethyl)phosphate	30 ng/L	215	72	0%	<30	<30	71	1%	32	<30	72	7%	43	<30
Tris(1,3-dichloro-2-propyl)phosphate	30 ng/L	215	72	26%	211	84	71	32%	139	70	72	29%	215	76
Bifenthrin	10 ng/L	215	72	1%	43	<10	71	0%	<10	<10	72	0%	<10	<10
Cypermethrin	90 ng/L	215	72	0%	<90	<90	71	0%	<90	<90	72	0%	<90	<90
Lambda-cyhalothrin	10 ng/L	215	72	0%	<10	<10	71	0%	<10	<10	72	0%	<10	<10
NO_3-N	0.1 ppm	323	108	45%	2.4	0.6	107	31%	2.1	0.2	108	56%	2.1	0.4
Soil Adsorption Ratio	0.1 (unitless)	323	108	15%	0.2	<0.1	107	25%	0.1	<0.1	108	22%	0.1	<0.1
B	0.01 ppm	323	108	6%	0.20	<0.01	107	0%	<0.01	<0.01	108	0%	<0.01	<0.01
Fe	0.01 ppm	323	108	16%	0.15	0.01	107	9%	0.03	<0.01	108	9%	0.05	<0.01
Cu	0.01 ppm	323	108	43%	0.18	0.03	107	4%	0.01	<0.01	108	6%	0.01	<0.01
Zn	0.01 ppm	323	108	19%	0.14	0.01	107	38%	0.10	0.02	108	6%	0.03	<0.01
Mn	0.01 ppm	323	108	10%	0.13	0.01	107	2%	0.01	<0.01	108	0%	<0.01	<0.01
Total Suspended Solids	1 mg/L	215	72	94%	89	52	71	79%	92	55	72	72%	68	47

Rainfall intensity played a significant role in water quality for all parameters listed in Table 2-21. The 64 mm/hr intensity was significantly different from the other intensities for the majority of parameters; only the Σ17PAHs (QL >300 ng/L) were similar between the 64 and 28 mm/hr simulations. The 38 and 28 mm/hr intensities were not significantly different for the following: SAR, Fe, Cu, and benzo(a)pyrene concentrations. Significant differences across all three intensities were observed for the following: NO_3-N, Zn, TSS (no data for 64 mm/hr), ΣCommonly Detected PAHs (QL >75 ng/), ΣCarcinogenic PAHs (QL >70 ng/L), TDCPP, and fluoranthene concentrations. Egodawatta et al. (2009) observed that finer particle sizes are bonded to roof surfaces and are only mobilized during relatively high rainfall intensity events. This could explain the differences observed TSS and PAHs concentrations between the different intensities.

The asphalt shingle roofs were significantly different from the metal and clay tile roofs for PAH, TSS, Cu, and Zn, concentrations. Van Metre and Mahler (2003) observed no evidence that asphalt shingles were a source of PAHs in urban runoff. Therefore, the PAHs observed in the roof runoff is likely due to atmospheric deposition. The rougher surface texture of asphalt shingles compared to the metal and clay tile materials appears to be the main reason why there was a significant difference in roofing material for PAH and TSS concentrations. The rougher surface texture of the shingles allow for particulates to be deposited in the various pore spaces within the rough surface. The Cu and Zn concentrations are most likely from both the nails used to install the asphalt shingles and the shingles themselves.

Significant differences were observed between sample one and all subsequent samples for all parameters except SAR, Zn, and TDCPP, indicating a first-flush effect for the majority of the parameters. Significant differences were observed between samples two and three for TSS, ΣCarcinogenic PAHs, fluoranthene, and benzo(a)pyrene.

Seven correlation matrices were calculated to compare SIM water quality results. Table 2-23 lists the critical values used to determine whether a correlation existed between parameters. SIM correlation matrices are shown in Tables 2-24 to 2-30; the plus sign indicates a positive correlation and a minus sign shows a negative correlation while gray indicates no correlation and black indicates there were no detections above the reporting limit and therefore no correlation could be calculated. Actual Spearman's rho values reported can be found in Appendix E.

Table 2-23. Critical Student's t and Spearman's Rho (rs) values for SIM correlation matrices (α = 0.05).

Correlation Matrix	**n**	**df (n-2)**	**Student's t**	**Critical r_s value**
Inorganics – All Simulations, All Roofs	323	321	1.646	0.091
Organics – All Simulations, All Roofs	215	213	1.646	0.112
Inorganics – 64 mm/hr, All Roofs	108	106	1.659	0.159
Organics – 64 mm/hr, All Roofs	72	70	1.667	0.195
Inorganics – 38 mm/hr, All Roofs	108	106	1.659	0.159
Organics – 38 mm/hr, All Roofs	72	70	1.667	0.195
Inorganics – 28 mm/hr, All Roofs	107	105	1.660	0.160
Organics – 28 mm/hr, All Roofs	71	69	1.667	0.197
Inorganics – Asphalt, All Simulations	108	106	1.659	0.159
Organics – Asphalt, All Simulations	72	70	1.667	0.195
Inorganics – Clay Tile, All Simulations	108	106	1.659	0.159
Organics – Clay Tile, All Simulations	72	70	1.667	0.195
Inorganics – Metal, All Simulations	107	105	1.660	0.160
Organics – Metal, All Simulations	71	69	1.667	0.197

In general, the majority of parameters were positively correlated with one another when comparing results from all roofs and all three simulations (Table 2-24), with exceptions to some comparisons for pH and SAR. Bifenthrin showed no correlation to any parameters (cypermethrin and lambda-cyhalothrin had no detections in SIM samples). Positive correlations were observed to exist between all PAH detections, TSS, turbidity, and EC for all SIM matrix comparisons.

Table 2-24. Correlation matrix based on Spearman's Rho values (α = 0.05) for the simulated rainfall events when combining results from all roof types and intensities together.

	pH	EC	NO_3-N	SAR	B	Fe	Cu	Zn	Mn	TSS	Turbidity	Σ17PAHs	ΣCommonly Detected PAHs	ΣCarcinogenic PAHs	TCEP	TDCPP	Bifenthrin	Cypermethrin	Lambda-cyhalothrin	Fluoranthene
pH																				
EC	+																			
NO_3-N	+	+																		
SAR	+	+	0																	
B	-	+	+	+																
Fe	0	+	+	0	+															
Cu	-	+	+	+	+	+														
Zn	0	+	+	+	+	+	+													
Mn	-	+	+	0	+	+	+	+												
TSS	+	+	+	-	0	+	+	+	+											
Turbidity	+	+	+	-	+	+	+	+	+	+										
Σ17PAHs	0	+	0	-	+	+	+	+	+	+	+									
ΣCommonly Detected PAHs	+	+	0	-	+	+	+	+	+	+	+	+								
ΣCarcinogenic PAHs	+	+	0	-	+	+	+	+	+	+	+	+	+							
TCEP	0	+	+	0	0	+	0	+	0	*	+	+	+	+						
TDCPP	0	+	+	+	+	+	+	+	+	+	+	+	+	+	+					
Bifenthrin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
Cypermethrin	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*			
Lambda-cyhalothrin	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		
Fluoranthene	0	+	+	0	+	+	+	+	+	+	+	+	+	+	+	+	0	*	*	
Benzo(a)pyrene	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+	0	*	*	+

Note: A positive sign (+) indicates a positive correlation existed, a negative sign (-) indicates a negative correlation existed, a zero (0) indicates no correlation existed, and an asterisk (*) indicates that a correlation could not be performed due to one or both of the two compared groups being composed entire of non-detects. EC = conductivity, SAR = soil adsorption ratio, TSS = total suspended solids, TCEP = tris(2-chloroethyl) phosphate, TDCPP = tris(1,3-dichloro-2-propyl) phosphate. Σ17PAHs includes naphthalene, 2-methyl naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene, and benzo(g,h,i)perylene. ΣCommonly Detected PAHs includes fluoranthene, pyrene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, and ideno(1,2,3-cd)pyrene. ΣCarcinogenic PAHs includes benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene.

Table 2-25. Correlation matrix based on Spearman's Rho values (α = 0.05) for the simulated rainfall events when combining results from all roof types for the 64 mm/hr simulation event.

	pH	EC	NO_3-N	SAR	B	Fe	Cu	Zn	Mn	TSS	Turbidity	Σ17PAHs	ΣCommonly Detected PAHs	ΣCarcinogenic PAHs	TCEP	TDCPP	Bifenthrin	Cypermethrin	Lambda-cyhalothrin	Fluoranthene
pH																				
EC	-																			
NO_3-N	-	+																		
SAR	0	-	-																	
B	-	+	+	0																
Fe	-	+	+	-	+															
Cu	-	+	+	0	+	+														
Zn	-	+	+	-	+	+	+													
Mn	-	+	+	0	+	+	+	+												
TSS	*	*	*	*	*	*	*	*	*	*										
Turbidity	-	+	+	-	+	+	+	+	+	*										
Σ17PAHs	-	+	+	-	+	+	+	+	+	*	+									
ΣCommonly Detected PAHs	-	+	+	-	+	+	+	+	+	*	+	+								
ΣCarcinogenic PAHs	-	+	+	-	+	+	+	+	+	*	+	+	+							
TCEP	0	+	+	-	0	+	0	0	0	*	+	+	+	+						
TDCPP	-	+	+	-	0	+	+	+	0	*	+	+	+	+	+					
Bifenthrin	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*				
Cypermethrin	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*			
Lambda-cyhalothrin	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		
Fluoranthene	-	+	+	-	+	+	+	+	+	*	+	+	+	+	+	+	*	*	*	
Benzo(a)pyrene	-	+	+	-	+	+	+	+	+	*	+	+	+	+	+	+	*	*	*	+

Note: A positive sign (+) indicates a positive correlation existed, a negative sign (-) indicates a negative correlation existed, a zero (0) indicates no correlation existed, and an asterisk (*) indicates that a correlation could not be performed due to one or both of the two compared groups being composed entire of non-detects. EC = conductivity, SAR = soil adsorption ratio, TSS = total suspended solids, TCEP = tris(2-chloroethyl) phosphate, TDCPP = tris(1,3-dichloro-2-propyl) phosphate. Σ17PAHs includes naphthalene, 2-methyl naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene, and benzo(g,h,i)perylene. ΣCommonly Detected PAHs includes fluoranthene, pyrene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, and ideno(1,2,3-cd)pyrene. ΣCarcinogenic PAHs includes benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene.

Table 2-26. Correlation matrix based on Spearman's Rho values ($\alpha = 0.05$) for the simulated rainfall events when combining results from all roof types for the 38 mm/hr simulation event.

	pH	EC	NO_3-N	SAR	B	Fe	Cu	Zn	Mn	TSS	Turbidity	Σ17PAHs	ΣCommonly Detected PAHs	ΣCarcinogenic PAHs	TCEP	TDCPP	Bifenthrin	Cypermethrin	Lambda-cyhalothrin	Fluoranthene
pH																				
EC	+																			
NO_3-N	+	+																		
SAR	0	-	0																	
B	*	*	*	*																
Fe	+	+	+	0	*															
Cu	0	+	+	0	*	+														
Zn	0	0	0	0	*	+	0													
Mn	+	+	+	0	*	+	+	0												
TSS	+	+	+	-	*	+	+	0	+											
Turbidity	+	+	+	-	*	+	+	0	+	+										
Σ17PAHs	+	+	+	0	*	0	0	0	0	+	+									
ΣCommonly Detected PAHs	+	+	+	0	*	+	+	0	+	+	+	+								
ΣCarcinogenic PAHs	+	+	+	0	*	+	+	0	+	+	+	+	+							
TCEP	*	*	*	*	*	*	*	*	*	*	*	*	*	*						
TDCPP	0	0	0	0	*	0	0	+	0	0	0	0	0	0	*					
Bifenthrin	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*				
Cypermethrin	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*			
Lambda-cyhalothrin	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		
Fluoranthene	+	+	+	0	*	+	+	0	+	+	+	+	+	+	*	0	*	*	*	
Benzo(a)pyrene	+	+	+	0	*	+	+	0	+	+	+	+	+	+	*	0	*	*	*	+

Note: A positive sign (+) indicates a positive correlation existed, a negative sign (-) indicates a negative correlation existed, a zero (0) indicates no correlation existed, and an asterisk (*) indicates that a correlation could not be performed due to one or both of the two compared groups being composed entire of non-detects. EC = conductivity, SAR = soil adsorption ratio, TSS = total suspended solids, TCEP = tris(2-chloroethyl) phosphate, TDCPP = tris(1,3-dichloro-2-propyl) phosphate. Σ17PAHs includes naphthalene, 2-methyl naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene, and benzo(g,h,i)perylene. ΣCommonly Detected PAHs includes fluoranthene, pyrene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, and ideno(1,2,3-cd)pyrene. ΣCarcinogenic PAHs includes benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene.

Table 2-27. Correlation matrix based on Spearman's Rho values ($\alpha = 0.05$) for the simulated rainfall events when combining results from all roof types for the 28 mm/hr simulation event.

	pH	EC	NO_3-N	SAR	B	Fe	Cu	Zn	Mn	TSS	Turbidity	Σ17PAHs	ΣCommonly Detected PAHs	ΣCarcinogenic PAHs	TCEP	TDCPP	Bifenthrin	Cypermethrin	Lambda-cyhalothrin	Fluoranthene
pH																				
EC	+																			
NO_3-N	+	+																		
SAR	*	*	*																	
B	*	*	*	*																
Fe	+	+	+	*	*															
Cu	+	+	+	*	*	0														
Zn	0	0	0	*	*	0	0													
Mn	0	0	0	*	*	0	+	+												
TSS	+	+	+	*	*	+	+	0	0											
Turbidity	+	+	+	*	*	+	+	0	0	+										
Σ17PAHs	+	+	+	*	*	+	+	0	0	+	+									
ΣCommonly Detected PAHs	+	+	+	*	*	+	+	0	0	+	+	+								
ΣCarcinogenic PAHs	+	+	+	*	*	+	+	0	0	+	+	+	+							
TCEP	*	*	*	*	*	*	*	*	*	*	*	*	*	*						
TDCPP	0	0	+	*	*	0	0	0	0	+	0	+	+	+	*					
Bifenthrin	0	0	0	*	*	0	0	0	0	0	0	0	0	0	*	0				
Cypermethrin	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*			
Lambda-cyhalothrin	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		
Fluoranthene	+	+	+	*	*	+	+	0	0	+	+	+	+	+	*	0	0	*	*	
Benzo(a)pyrene	+	+	+	*	*	+	+	0	0	+	+	+	+	+	*	+	0	*	*	+

Note: A positive sign (+) indicates a positive correlation existed, a negative sign (-) indicates a negative correlation existed, a zero (0) indicates no correlation existed, and an asterisk (*) indicates that a correlation could not be performed due to one or both of the two compared groups being composed entire of non-detects. EC = conductivity, SAR = soil adsorption ratio, TSS = total suspended solids, TCEP = tris(2-chloroethyl) phosphate, TDCPP = tris(1,3-dichloro-2-propyl) phosphate. Σ17PAHs includes naphthalene, 2-methyl naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene, and benzo(g,h,i)perylene. ΣCommonly Detected PAHs includes fluoranthene, pyrene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, and ideno(1,2,3-cd)pyrene. ΣCarcinogenic PAHs includes benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene.

Table 2-28. Correlation matrix based on Spearman's Rho values ($\alpha = 0.05$) for the simulated rainfall events when combining results from the asphalt shingle roofs from all simulations events combined.

	pH	EC	NO_3-N	SAR	B	Fe	Cu	Zn	Mn	TSS	Turbidity	Σ17PAHs	ΣCommonly Detected PAHs	ΣCarcinogenic PAHs	TCEP	TDCPP	Bifenthrin	Cypermethrin	Lambda-cyhalothrin	Fluoranthene
pH																				
EC	0																			
NO_3-N	0	+																		
SAR	-	+	0																	
B	-	+	+	+																
Fe	-	+	+	+	+															
Cu	0	+	+	+	+	+														
Zn	-	+	+	+	+	+	+													
Mn	-	+	+	+	+	+	+	+												
TSS	+	+	+	*	*	+	+	*	+											
Turbidity	0	+	+	0	+	+	+	+	+	+										
Σ17PAHs	-	+	+	0	+	+	+	+	+	+	+									
ΣCommonly Detected PAHs	0	+	+	0	+	+	+	+	+	+	+	+								
ΣCarcinogenic PAHs	-	+	+	0	+	+	+	+	+	+	+	+	+							
TCEP	*	*	*	*	*	*	*	*	*	*	*	*	*	*						
TDCPP	-	+	+	+	+	+	+	+	+	*	+	+	+	+	*					
Bifenthrin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*					
Cypermethrin	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*			
Lambda-cyhalothrin	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		
Fluoranthene	-	+	+	+	+	+	+	+	+	+	+	+	+	+	*	+	0	*	*	
Benzo(a)pyrene	0	+	0	0	+	+	+	+	+	+	+	+	+	+	*	+	0	*	*	+

Note: A positive sign (+) indicates a positive correlation existed, a negative sign (-) indicates a negative correlation existed, a zero (0) indicates no correlation existed, and an asterisk (*) indicates that a correlation could not be performed due to one or both of the two compared groups being composed entire of non-detects. EC = conductivity, SAR = soil adsorption ratio, TSS = total suspended solids, TCEP = tris(2-chloroethyl) phosphate, TDCPP = tris(1,3-dichloro-2-propyl) phosphate. Σ17PAHs includes naphthalene, 2-methyl naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene, and benzo(g,h,i)perylene. ΣCommonly Detected PAHs includes fluoranthene, pyrene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, and ideno(1,2,3-cd)pyrene. ΣCarcinogenic PAHs includes benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene.

Table 2-29. Correlation matrix based on Spearman's Rho values ($\alpha = 0.05$) for the simulated rainfall events when combining results from the clay tile roofs from all simulations events combined.

	pH	EC	NO_3-N	SAR	B	Fe	Cu	Zn	Mn	TSS	Turbidity	Σ17PAHs	ΣCommonly Detected PAHs	ΣCarcinogenic PAHs	TCEP	TDCPP	Bifenthrin	Cypermethrin	Lambda-cyhalothrin	Fluoranthene
pH																				
EC	+																			
NO_3-N	+	+																		
SAR	+	+																		
B	*	*	*	*																
Fe	0	+	+	0	*															
Cu	0	+		+	*	+														
Zn	0	+	+	0	*	+	+													
Mn	*	*	*	*	*	*	*	*												
TSS	+	+	+	*	*	+	-	*	*											
Turbidity	+	+	+	-	*	+	-		*	+										
Σ17PAHs	+	+	+	-	*	+	-	+	*	+	+									
ΣCommonly Detected PAHs	+	+	+	-	*	+	-	+	*	+	+	+								
ΣCarcinogenic PAHs	+	+	+	-	*	+	-	+	*	+	+	+	+							
TCEP	0	+	+	0	*	+	+	+	*	*	+	+	+	+						
TDCPP	0	+	+	0	*	+	+	+	*	+	+	+	+	+	+					
Bifenthrin	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*				
Cypermethrin	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*			
Lambda-cyhalothrin	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		
Fluoranthene	+	+	+	-	*	+	-	+	*	+	+	+	+	+	+	+	*	*	*	
Benzo(a)pyrene	+	+	+	-	*	+	-	+	*	+	+	+	+	+	+	+	*	*	*	+

Note: A positive sign (+) indicates a positive correlation existed, a negative sign (-) indicates a negative correlation existed, a zero (0) indicates no correlation existed, and an asterisk (*) indicates that a correlation could not be performed due to one or both of the two compared groups being composed entire of non-detects. EC = conductivity, SAR = soil adsorption ratio, TSS = total suspended solids, TCEP = tris(2-chloroethyl) phosphate, TDCPP = tris(1,3-dichloro-2-propyl) phosphate. Σ17PAHs includes naphthalene**,** 2-methyl naphthalene**,** acenaphthylene**,** acenaphthene**,** fluorene**,** phenanthrene**,** anthracene**,** fluoranthene**,** pyrene**,** benz(a)anthracene**,** chrysene**,** benzo(b)fluoranthene**,** benzo(k)fluoranthene**,** benzo(a)pyrene**,** ideno(1,2,3-cd)pyrene**,** dibenz(a,h)anthracene**,** and benzo(g,h,i)perylene. ΣCommonly Detected PAHs includes fluoranthene, pyrene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, and ideno(1,2,3-cd)pyrene. ΣCarcinogenic PAHs includes benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene.

Table 2-30. Correlation matrix based on Spearman's Rho values (α = 0.05) for the simulated rainfall events when combining results from the metal roofs from all simulations events combined.

	pH	EC	NO_3-N	SAR	B	Fe	Cu	Zn	Mn	TSS	Turbidity	Σ17PAHs	ΣCommonly Detected PAHs	ΣCarcinogenic PAHs	TCEP	TDCPP	Bifenthrin	Cypermethrin	Lambda-cyhalothrin	Fluoranthene
pH																				
EC	+																			
NO_3-N	+	+																		
SAR	0	+	0																	
B	*	*	*	*																
Fe	+	+	+	-	*															
Cu	0	0	+	0	*	+														
Zn	0	+	+	0	*	+	+													
Mn	0	0	0	0	*	+	+	0												
TSS	+	+	+	0	*	+	0	+	0											
Turbidity	+	+	+	0	*	+	0	+	0	+										
Σ17PAHs	+	+	+	-	*	+	-	+	0	+	+									
ΣCommonly Detected PAHs	+	+	+	-	*	+	-	+	0	+	+	+								
ΣCarcinogenic PAHs	+	+	+	-	*	+	-	+	0	+	+	+	+							
TCEP	0	+	+	0	*	+	+	+	0	*	0	+	+	+						
TDCPP	0	+	+	0	*	+	-	+	0	0	+	0	0	0	0					
Bifenthrin	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*				
Cypermethrin	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*			
Lambda-cyhalothrin	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		
Fluoranthene	+	+	+	-	*	+	-	+	0	+	+	+	+	+	0	+	*	*	*	
Benzo(a)pyrene	+	+	+	-	*	+	-	+	0	+	+	+	+	+	+	0	*	*	*	+

Note: A positive sign (+) indicates a positive correlation existed, a negative sign (-) indicates a negative correlation existed, a zero (0) indicates no correlation existed, and an asterisk (*) indicates that a correlation could not be performed due to one or both of the two compared groups being composed entire of non-detects. EC = conductivity, SAR = soil adsorption ratio, TSS = total suspended solids, TCEP = tris(2-chloroethyl) phosphate, TDCPP = tris(1,3-dichloro-2-propyl) phosphate. Σ17PAHs includes naphthalene, 2-methyl naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene, and benzo(g,h,i)perylene. ΣCommonly Detected PAHs includes fluoranthene, pyrene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, and ideno(1,2,3-cd)pyrene. ΣCarcinogenic PAHs includes benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene.

2.4.3.2 Oklahoma City Field Sampling

Attempts were made to collect six pairs of samples from each roof during a storm event to characterize the roof runoff. Since samples were taken at pre-programmed time intervals, it was not always guaranteed that samples would be taken while the runoff was flowing. This resulted in not having six pairs of samples from each roof; some pairs had to be eliminated from events as they were shown to be taken when there was no runoff flowing from the roof (i.e. the rainfall had ceased temporarily or had ceased all together).

Descriptive statistics for the average pH, EC, turbidity, and TSS concentrations for OKC samples based on roof and runoff depth are shown in Table 2-31. As individual samples from each roof were not taken at the same runoff depth as the other roofs, the samples were grouped and analyzed by runoff depth categories. The runoff depth categories were: 0 – 0.66, 0.66 – 1.00, 1.00 – 1.33, 1.32 – 1.66, 1.66 – 3.00, 3.00 – 6.00, and 6.00 – 27 mm.

Pair-wise comparisons were made on OKC samples based on roof type and runoff depth, with the ADP as a covariate, using Tukey-Kramer in Minitab. Comparisons were not made for B, Mn, bifenthrin, or cypermethrin due to either low frequency of detection or non-detection. Tukey-Kramer was not performed on the censored SAR, TCEP, or lambda-cyhalothrin data due to Kruskal-Walis results showing no significant difference existed for either roof type or runoff depth. Table 2-40 provides an ANOVA summary on the OKC samples. When comparing samples based on runoff depth, all parameters and constituents were observed to not be significantly different when comparing initial runoff depths to later runoff depths. This is most likely due to the variability in rainfall intensities throughout a single storm event in OKC. The OKC storm events may have started off with a light rain, followed by an intense downpour, with small periods of light or no rainfall throughout, thereby washing off particulates from the roofs at different rates. These results are opposite from the SIM study, where the rainfall intensities were constant throughout each event.

Table 2-31. Descriptive statistics for the asphalt shingle, metal, and tar and gravel roofs at the OKC site.

	Sample Size			**Mean pH**			**Mean EC (µS/cm)**			**Mean Turbidity (NTU)**			**Mean TSS (mg/L)**		
Runoff Depth (mm)	Asphalt Shingle	Metal	Tar and Gravel	Asphalt Shingle	Metal	Tar and Gravel	Asphalt Shingle	Metal	Tar and Gravel	Asphalt Shingle	Metal	Tar and Gravel	Asphalt Shingle	Metal	Tar and Gravel
0.66	**3**	**4**	**12**	**7.3**	**6.8**	**7.1**	**132**	**99**	**58**	**14**	**14**	**14**	**31**	**29**	**20**
±Std. Dev.				0.16	0.03	0.23	13	61	29	5.2	1.9	5.4	17	6	18
1.00	**2**	**5**	**4**	**7.0**	**6.8**	**7.2**	**78**	**40**	**61**	**9.4**	**12**	**7.8**	**42**	**26**	**12**
±Std. Dev.				0.36	0.25	0.16	14	12	29	7.8	3.9	3.1	9.2	11	5.0
1.33	**-**	**8**	**2**	**-**	**7.1**	**7.1**	**-**	**39**	**52**	**-**	**10**	**9.4**	**-**	**24**	**13**
±Std. Dev.				-	0.21	0.0	-	18	7	-	9.6	5.3	-	16	1.4
1.66	**2**	**5**	**1**	**6.8**	**6.7**	**7.2**	**118**	**28**	**46**	**35**	**6.1**	**6.7**	**71**	**17**	**11**
±Std. Dev.				0.40	0.27	0.0	71	6	0.0	1.8	4.3	0.0	21	7	0.0
3.00	**5**	**4**	**3**	**6.9**	**6.5**	**6.7**	**55**	**21**	**23**	**8.4**	**4.6**	**13**	**31**	**10**	**23**
±Std. Dev.				0.22	0.30	0.29	34	1	9	7.4	2.2	7.9	13	3	16
6.00	**5**	**6**	**-**	**6.5**	**6.4**	**-**	**27**	**19**	**-**	**7.0**	**5.2**	**-**	**24**	**11**	**-**
±Std. Dev.				0.40	0.35	-	8	5	-	5.3	3.2	-	19	13	-
27.0	**4**	**7**	**-**	**6.8**	**6.2**	**-**	**28**	**17**	**-**	**6.9**	**3.0**	**-**	**15**	**6**	**-**
±Std. Dev.				0.15	0.23	-	10	10	-	0.8	1.4	-	9.2	3	-

Tables 2-32 through 2-39 provide summaries and statistical comparison results for the OKC samples based on roof type and runoff depth for pH, conductivity, turbidity, and TSS measurements. Table 2-40 provides a summary of all of the Tukey-Kramer results in the form of an ANOVA table for the OKC samples.

Table 2-32. pH and statistical comparisons between roof types sampled from the OKC site. Different letters in the ANOVA column indicate there was a significant difference between samples.

Roof Type	pH Mean	ANOVA Results (α = 0.05)
Asphalt Shingle	6.80	A
Metal	6.55	B
Tar & Gravel	7.04	A

Table 2-33. pH and statistical comparisons between runoff depths from roof runoff sampled in OKC. Different letters in the ANOVA column indicate there was a significant difference between samples.

Runoff Depth (mm)	pH Mean	ANOVA Results (α = 0.05)
0-0.66	7.04	AB
0.66-1.00	6.95	ABC
1.00-1.33	7.11	A
1.33-1.66	6.73	BCD
1.66-3.00	6.70	CDE
3.00-6.00	6.48	DE
6.00-27.0	6.32	E

Table 2-34. pH and statistical comparisons between roof types sampled from the OKC site. Different letters in the ANOVA column indicate there was a significant difference between samples.

Roof Type	Conductivity Mean μS/cm	ANOVA Results (α = 0.05)
Asphalt Shingle	62	A
Metal	35	B
Tar & Gravel	53	B

Table 2-35. Conductivity and statistical comparisons between runoff depths from roof runoff sampled in OKC. Different letters in the ANOVA column indicate there was a significant difference between samples.

Runoff Depth (mm)	Conductivity Mean µS/cm	ANOVA Results ($\alpha = 0.05$)
0-0.66	79	A
0.66-1.00	54	AB
1.00-1.33	42	ABC
1.33-1.66	53	AB
1.66-3.00	35	BC
3.00-6.00	23	C
6.00-27.0	21	C

Table 2-36. Turbidity and statistical comparisons between roof types sampled from the OKC site. Different letters in the ANOVA column indicate there was a significant difference between samples.

Roof Type	Turbidity Mean NTU	ANOVA Results ($\alpha = 0.05$)
Asphalt Shingle	11.3	A
Metal	7.73	B
Tar & Gravel	11.9	AB

Table 2-37. Turbidity and statistical comparisons between runoff depths from roof runoff sampled in OKC. Different letters in the ANOVA column indicate there was a significant difference between samples.

Runoff Depth (mm)	Turbidity Mean (NTU)	ANOVA Results ($\alpha = 0.05$)
0-0.66	14.1	AB
0.66-1.00	10.2	AB
1.00-1.33	10.0	AB
1.33-1.66	13.4	A
1.66-3.00	8.14	AB
3.00-6.00	6.03	AB
6.00-27.0	4.43	B

Table 2-38. Total suspended solids and statistical comparisons between roof types sampled from the OKC site. Different letters in the ANOVA column indicate there was a significant difference between samples.

Roof Type	Total Suspended Solids Mean (mg/L)	ANOVA Results (α = 0.05)
Asphalt Shingle	31	A
Metal	17	B
Tar & Gravel	18	B

Table 2-39. Total suspended solids and statistical comparisons between runoff depths from roof runoff sampled in OKC. Different letters in the ANOVA column indicate there was a significant difference between samples.

Runoff Depth (mm)	Total Suspended Solids Mean (mg/L)	ANOVA Results (α = 0.05)
0-0.66	24	AB
0.66-1.00	24	AB
1.00-1.33	22	AB
1.33-1.66	30	A
1.66-3.00	22	AB
3.00-6.00	17	AB
6.00-27.0	9	B

Table 2-40. ANOVA summary (α = 0.05) for OKC field samples based on roof and runoff depth.

	Roof			Runoff Depth (mm)						
	Asphalt Shingle	**Metal**	**Tar & Gravel**	**0.66**	**1.00**	**1.33**	**1.66**	**3.00**	**6.00**	**27.0**
Sample Size	**21**	**39**	**22**	**19**	**11**	**10**	**8**	**12**	**11**	**11**
pH	A	B	A	AB	ABC	A	BCD	CDE	DE	E
EC	A	B	B	A	AB	ABC	AB	BC	C	C
Turbidity	A	B	AB	AB	AB	AB	A	AB	AB	B
Total Suspended Solids	A	B	B	AB	AB	AB	A	AB	AB	B
NO_3-N	A	B	AB	A	AB	AB	AB	B	B	B
Fe	AB	B	A	A	A	A	A	A	A	A
Cu	A	B	B	A	AB	ABC	ABC	ABC	C	BC
Zn	A	A	B	A	A	A	A	A	A	A
Sample Size	**13**	**18**	**10**	**10**	**5**	**0**	**3**	**7**	**7**	**9**
Total Coliforms	A	A	A	A	A	-	A	A	A	A
E. coli	AB	B	A	A	A	-	A	A	A	A
Sample Size	**21**	**39**	**22**	**22**	**10**	**11**	**6**	**13**	**9**	**11**
∑17PAHs	A	B	C	A	A	AB	AB	AB	BC	C
∑Commonly Detected PAHs	A	B	C	A	A	AB	A	AB	BC	C
∑Carcinogenic PAHs	A	B	B	A	A	A	A	A	AB	B
Fluoranthene	A	B	C	A	A	AB	A	ABC	BC	C
Benzo(a)pyrene	A	B	C	A	A	AB	AB	AB	BC	C
TDCPP	A	A	B	A	AB	B	AB	AB	AB	AB

Σ17PAHs includes naphthalene, 2-methyl naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene, and benzo(g,h,i)perylene. ΣCommonly Detected PAHs includes fluoranthene, pyrene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, and ideno(1,2,3-cd)pyrene . ΣCarcinogenic PAHs includes benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene

Ambient rainfall samples were not collected during storm events at the OKC site for comparisons between ambient conditions and roof runoff. However, the average pH of rainfall for central Oklahoma has been reported to be 6.4 (Sharpley et al. 1984). When comparing results to the average pH of rainfall in Oklahoma, all three OKC roofs appeared to have a neutralizing effect on the rainfall. The pH from the metal roof runoff was significantly different the asphalt shingle and tar and gravel roofs, while the pH from the asphalt shingle and tar and gravel roof runoff were statistically the same. The interquartile range and outliers for pH based on roof type are shown in Figure 2-13.

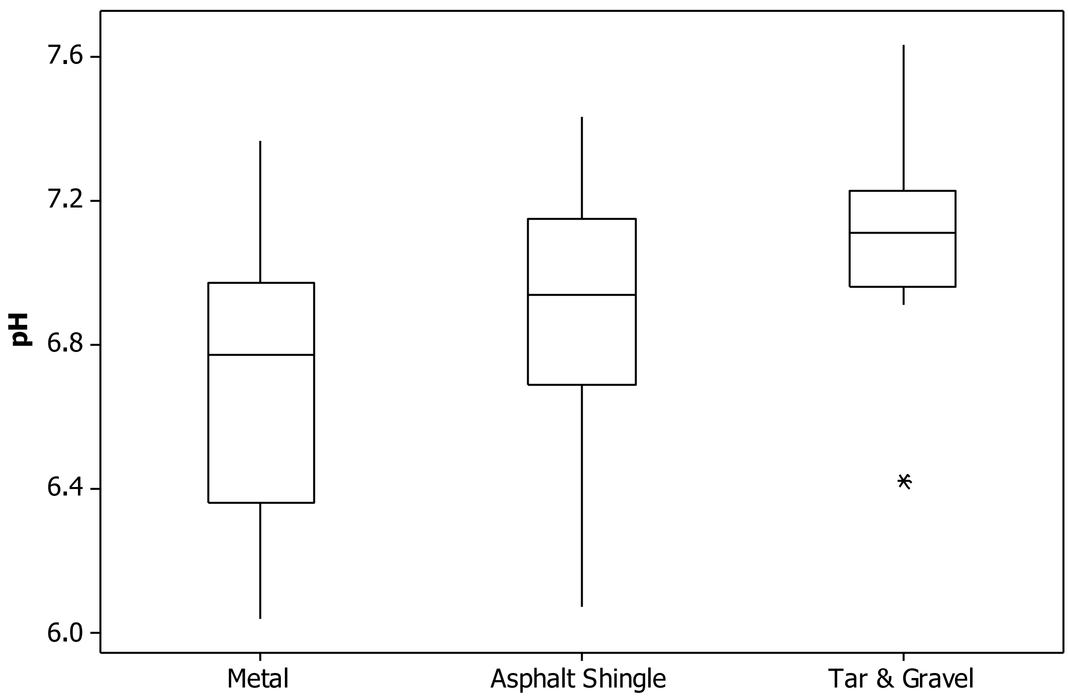

Figure 2-13. Comparison of pH between OKC roofs based on roof type.

The asphalt shingle roof had significantly different EC and turbidity levels from the metal and tar and gravel roofs. Figure 2-14 shows the wider range in EC values observed in the asphalt shingle runoff compared to the other roofs. Figure 2-15 shows a comparison in turbidity levels between the three roofs. An average EC measurement of 34 µS/cm was observed in rainfall samples collected in an ambient sampler in Austin, TX, (Mendez et al. 2011). When comparing the observed EC values in this study to the average EC concentrations in Austin, TX, the results in Figure 14 show the roof runoff having higher EC measurements than the ambient rainfall.

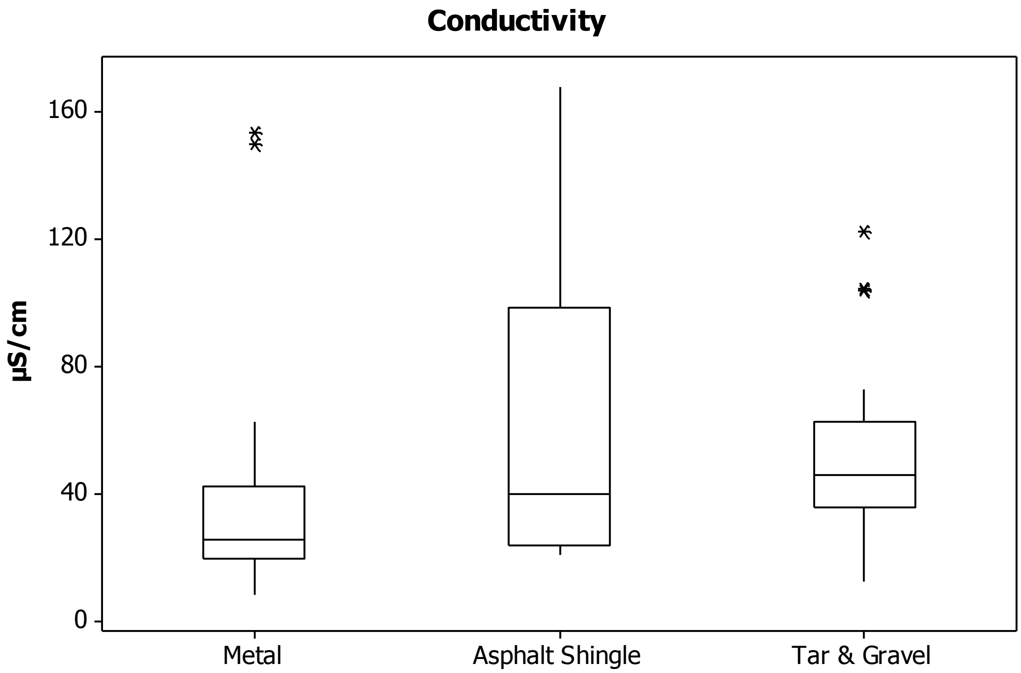

Figure 2-14. Comparison of conductivity between OKC roofs based on roof type.

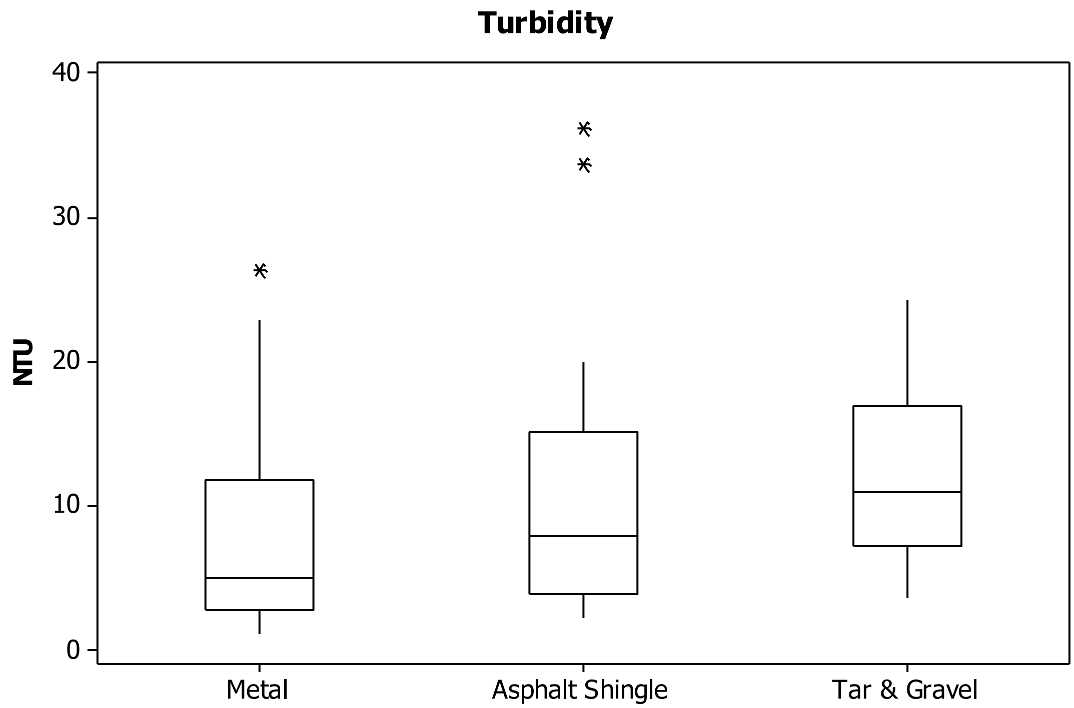

Figure 2-15. Comparison of turbidity between OKC roofs based on roof type.

The asphalt shingle roof runoff was significantly different from the metal and tar and gravel roofs when comparing TSS concentrations (Figure 2-16). It is hypothesized that the OKC TSS results based on runoff depths differ from the SIM results due to the varying intensities that occurred throughout a single OKC storm event. SIM samples had one intensity throughout each simulation, allowing for a more controlled and even wash off of any particles.

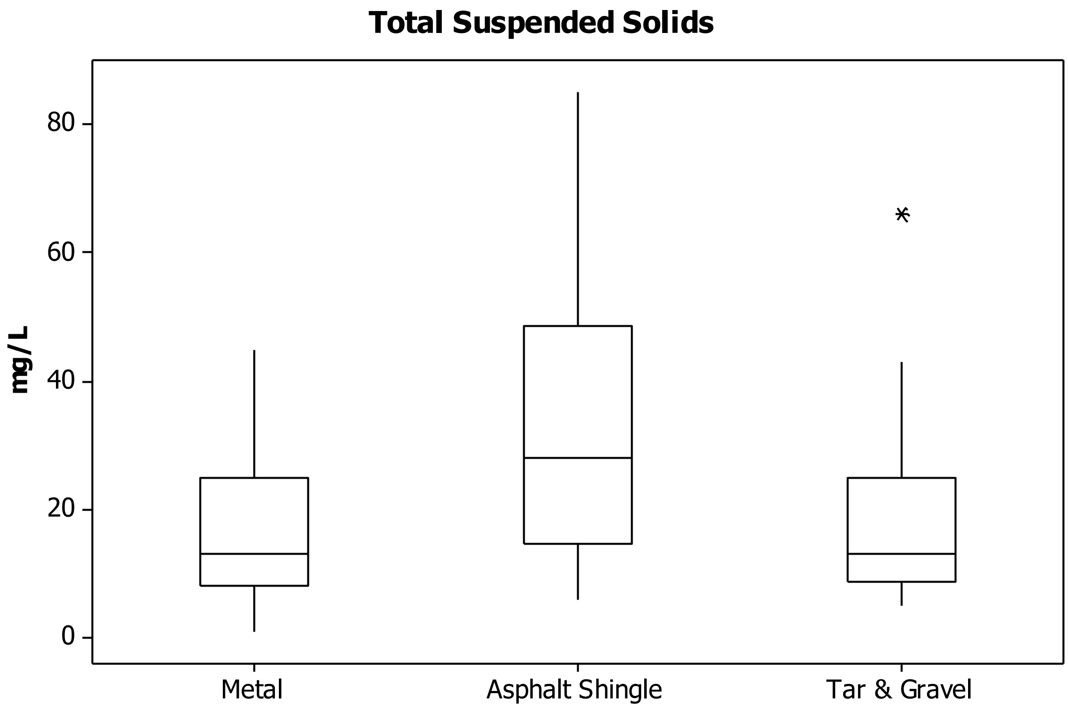

Figure 2-16. Comparison of total suspended solids between OKC roofs based on roof type.

Table 2-41 provides a descriptive summary of non-detects reported for both organic and inorganic compounds for OKC. Only samples that could be processed within 48 hours of collection were analyzed for total coliforms and *E. coli*. Of the light-weight PAHs, Pyrene had the highest frequency of detection for all three roofs. Fluoranthene had the second highest frequency of occurrence. The asphalt shingle roof runoff had higher concentrations of pyrene and fluroanthene than the metal and tar and gravel roofs. Of the carcinogenic PAHs, benzo(a)pyrene had greater detection frequencies in the asphalt shingle runoff, followed by metal, and then the tar and gravel runoff. Benzo(b)fluoranthene, another carcinogenic PAH, had the greatest detection in samples across all three roofs and was observed at higher concentrations than benzo(a)pyrene.

TCEP was observed in greater frequency than TDCPP for the asphalt shingle and metal roof runoff while TDCPP was more prevalent in the tar and gravel runoff. Lambda-cyhalothrin was the only pesticide detected in samples from the OKC site, with the highest concentration observed in the tar and gravel roof runoff.

NO_3-N was detected in all but one sample at the OKC site. Boron was only detected in 19% of asphalt shingle samples at concentrations below any level of concern relating to irrigation quality. The tar and gravel roof had the highest detection of Zn; this could be due to HVAC equipment located on top of the roof, which was not present on the asphalt shingle and metal roofs. The tar and gravel roof also had the highest detection and concentrations of *E. coli* in the samples tested. This could be attributed to the close proximity of trees to the tar and gravel roof, which allowed for an increased probability of contamination from birds, squirrels, or rodents (de Kwaadsteniet et al. 2013). The flat nature of the roof also allowed for higher levels of pollutants to accumulate over time without being washed away, as was observed by Farreny et al. (2011) when comparing runoff water quality between flat and sloped roofs.

Table 2-41. Water-quality summaries for field samples collected in Oklahoma City that contained non-detects.

			Asphalt Shingle				Metal				Tar & Gravel			
	RL	n Total	n	Freq. > RL	Max Value	90th Percentile	n	Freq. > RL	Max Value	90th Percentile	n	Freq. > RL	Max Value	90th Percentile
Naphthalene	30 ng/L	82	21	33%	147	56	39	26%	98	55	22	9%	59	26
2-Methylnaphthalene	30 ng/L	82	21	5%	62	<30	39	0%	<30	<30	22	0%	<30	<30
Acenaphthylene	30 ng/L	82	21	0%	<30	<30	39	0%	<30	<30	22	0%	<30	<30
Acenaphthene	30 ng/L	82	21	0%	<30	<30	39	0%	<30	<30	22	0%	<30	<30
Fluorene	30 ng/L	82	21	0%	<30	<30	39	0%	<30	<30	22	0%	<30	<30
Phenanthrene	30 ng/L	82	21	43%	141	77	39	18%	85	48	22	5%	50	<30
Anthracene	15 ng/L	82	21	5%	18	<15	39	3%	77	<15	22	0%	<15	<15
Fluoranthene	15 ng/L	82	21	90%	255	202	39	54%	148	100	22	32%	113	55
Pyrene	10 ng/L	82	21	95%	206	169	39	79%	124	84	22	73%	104	60
Benz(a)anthracene	10 ng/L	82	21	86%	116	92	39	33%	72	30	22	32%	39	27
Chrysene	10 ng/L	82	21	95%	149	126	39	69%	88	42	22	50%	77	43
Benzo(b)fluoranthene	10 ng/L	82	21	100%	209	185	39	77%	124	76	22	82%	122	62
Benzo(k)fluoranthene	10 ng/L	82	21	86%	61	57	39	41%	49	39	22	32%	47	30
Benzo(a)pyrene	10 ng/L	82	21	90%	104	89	39	49%	70	31	22	41%	54	33
Indeno(1,2,3-cd)pyrene	10 ng/L	82	21	90%	170	146	39	72%	88	48	22	55%	81	47
Dibenz(a,h)anthracene	10 ng/L	82	21	38%	26	22	39	5%	13	<10	22	0%	<10	<10
Benzo(g,h,i)perylene	10 ng/L	82	21	86%	109	73	39	59%	58	35	22	45%	46	27
∑17PAHs	>300 ng/L	82	21	67%	1448	1440	39	31%	955	517	22	14%	770	391
∑Commonly Detected PAHs	>75 ng/L	82	21	95%	1099	1012	39	54%	672	384	22	41%	598	327
∑Probable Carcinogenic PAHs	>70 ng/L	82	21	86%	760	728	39	46%	459	243	22	32%	420	236
Tris(2-chloroethyl)phosphate	30 ng/L	82	21	19%	126	64	39	26%	75	43	22	23%	42	38
Tris(1,3-dichloro-2-propyl)phosphate	30 ng/L	82	21	10%	45	25	39	10%	46	30	22	59%	57	47
Bifenthrin	10 ng/L	82	21	0%	<10	<10	39	0%	<10	<10	22	0%	<10	<10
Cypermethrin	90 ng/L	82	21	0%	<90	<90	39	0%	<90	<90	22	0%	<90	<90
Lambda-cyhalothrin	10 ng/L	82	21	14%	75	63	39	5%	15	<10	22	5%	117	<10
NO_3-N	0.1 ppm	82	21	100%	2.0	1.5	39	97%	1.0	0.9	22	100%	1.5	1.4
Soil Adsorption Ratio	0.1 (unitless)	82	21	90%	0.5	0.3	39	87%	0.9	0.4	22	82%	0.2	0.2
B	0.01 ppm	82	21	19%	0.10	0.10	39	0%	<0.01	<0.01	22	0%	<0.01	<0.01
Fe	0.01 ppm	82	21	100%	0.10	0.05	39	92%	0.03	0.03	22	86%	0.05	0.04
Cu	0.01 ppm	82	21	48%	0.07	0.05	39	5%	0.01	<0.01	22	18%	0.04	0.02
Zn	0.01 ppm	82	21	19%	0.03	0.02	39	41%	0.04	0.02	22	73%	0.24	0.10
Mn	0.01 ppm	82	21	33%	0.15	0.09	39	0%	<0.01	<0.01	22	5%	0.02	<0.01
Total Coliforms	<1/100 mL, >2419/100 mL	41	13	100%	>2419	2311	18	94%	2030	1652	10	100%	>2419	>2419
E. coli	<1/100 mL, >2419/100 mL	41	13	31%	100	74	18	17%	2	1.1	10	80%	411	396

Four Spearman's Rho correlation matrices were created to compare OKC water quality results. Table 2-42 lists the critical values used to determine whether a correlation existed. OKC correlation matrices are shown in Tables 2-43 to 2-46; the plus sign indicates a positive correlation and a minus sign shows a negative correlation while gray indicates no correlation and black indicates there were no detections above the reporting limit and therefore no correlation could be calculated. The actual Spearman's Rho values can be found in Appendix E.

Table 2-42. Critical Student's t and Spearman's Rho (r_s) values for OKC correlation matrices (α = 0.05).

Correlation Matrix	**n**	**df (n-2)**	**Student's t**	**Critical r_s value**
All Roofs – Inorganics & Organics	82	80	1.664	0.183
All Roofs – Bacteria Samples	41	39	1.685	0.261
A_{OKC} – Inorganics & Organics	21	19	1.729	0.369
A_{OKC} – Bacteria	13	11	1.796	0.476
M_{OKC} – Inorganics & Organics	39	37	1.687	0.267
M_{OKC} – Bacteria	18	16	1.746	0.400
TG – Inorganics & Organics	22	20	1.725	0.360
TG – Bacteria	10	8	1.860	0.549

OKC samples did not have as many positive correlations between parameters when comparing results from all three roofs together as the rainfall simulations did (Table 2-24). This is most likely due to the irregularity in sampling dates and times between the roofs. OKC comparisons based on roofing material are shown in Tables 2-43 to 2-46. As with the SIM samples, positive correlations were observed to exist between PAH detections, TSS, and turbidity for all matrix comparisons between OKC roofs. There were positive correlations between EC and PAHs, TSS, and turbidity for the asphalt shingle and metal roofs, with the only exception being EC having no correlation to the PAH fluoranthene for the metal roofs.

A study by Stein et al. (2006) showed a strong correlation to exist in an exponentially nonlinear manner between ADP and PAH concentration (r^2 = 0.79), load (r^2 = 0.81), and flux (r^2 = 0.54) observed in urban runoff. This correlation was not observed in the OKC study.

Table 2-43. Correlation matrix based on Spearman's Rho values ($\alpha = 0.05$) for the field sampling in OKC when combining results from all three roofs from all eleven storm events.

	ADP	pH	EC	NO_3-N	SAR	B	Fe	Cu	Zn	Mn	TSS	Turbidity	Total Coliforms	*E. coli*	Σ17PAHs	ΣCommonly Detected PAHs	ΣCarcinogenic PAHs	TCEP	TDCPP	Bifenthrin	Cypermethrin	Lambda-cyhalothrin	Fluoranthene
ADP																							
pH	0																						
EC	+	+																					
NO_3-N	0	+	+																				
SAR	+	0	+	+																			
B	0	0	+	+	+																		
Fe	0	0	0	0	0	0																	
Cu	0	+	+	+	0	+	+																
Zn	+	0	0	+	0	0	+	0															
Mn	0	0	+	+	+	+	+	+	0														
TSS	0	+	+	+		+	+	+	0	+													
Turbidity	+	+	+	+	+	+	0	+	+	+	+												
Total Coliforms	-	+	0	0	-	0	0	0	0	0	0	0											
E. coli	0	+	0	0	-	0	+	0	0	0	0	+	+										
Σ17PAHs	0	0	+	0	0	+	0	+	0	+	+	+	0	0									
ΣCommonly Detected PAHs	0	0	+	0	0	+	0	+	0	+	+	+	0	0	+								
ΣCarcinogenic PAHs	0	0	+	0	0	+	0	+	0	+	+	+	0	0	+	+							
TCEP	+	0	+	+	+	+	0	0	0	+	0	+	-	0	0	0	0						
TDCPP	+	+	+	+	0	0	0	0	+		0	+	0	+	0	0	0	+					
Bifenthrin	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*				
Cypermethrin	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*			
Lambda-cyhalothrin	0	0	0	0	0	0	+	+	0	0	+	+	0	0	+	+	+	0	+	*	*		
Fluoranthene	0	0	+	0	0	+	0	+	0	+	+	+	0	0	+	+	+	0	0	*	*	+	
Benzo(a)pyrene	0	+	+	0	0	+	0	+	0	+	+	+	0	0	+	+	+	0	0	*	*	+	+

Note: A positive sign (+) indicates a positive correlation existed, a negative sign (-) indicates a negative correlation existed, a zero (0) indicates no correlation existed, and an asterisk (*) indicates that a correlation could not be performed due to one or both of the two compared groups being composed entire of non-detects. ADP = antecedent dry period, EC = conductivity, SAR = soil adsorption ratio, TSS = total suspended solids, TCEP = tris(2-chloroethyl) phosphate, TDCPP = tris(1,3-dichloro-2-propyl) phosphate. Σ17PAHs includes naphthalene, 2-methyl naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene, and benzo(g,h,i)perylene. ΣCommonly Detected PAHs includes fluoranthene, pyrene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, and ideno(1,2,3-cd)pyrene. ΣCarcinogenic PAHs includes benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene.

Table 2-44. Correlation matrix based on Spearman's Rho values (α = 0.05) for the field sampling in OKC when combining results from the tar and gravel roof from all storm events that had samples collected from tar and gravel roof.

	ADP	pH	EC	NO_3-N	SAR	B	Fe	Cu	Zn	Mn	TSS	Turbidity	Total Coliforms	*E. coli*	Σ17PAHs	ΣCommonly Detected PAHs	ΣCarcinogenic PAHs	TCEP	TDCPP	Bifenthrin	Cypermethrin	Lambda-cyhalothrin	Fluoranthene
ADP																							
pH	0																						
EC	0	+																					
NO_3-N	+	+	+																				
SAR	0	+	+	+																			
B	*	*	*	*	*																		
Fe	-	0	0	0	-	*																	
Cu	0	0	0	0	0	*	0																
Zn	0	0	0	0	0	*	+	+															
Mn	0	0	0	0	0	*	0	0	0														
TSS	0	0	0	0	0	*	+	0	0	0													
Turbidity	0	0	0	+	0	*	0	0	0	0	+												
Total Coliforms	-	+	+	0	+	*	-	0	-	0	0	0											
E. coli	-	0	0	0	0	*	0	0	0	0	0	0	0										
Σ17PAHs	0	-	0	0	+	*	0	0	0	+	+	+	0	0									
ΣCommonly Detected PAHs	0	0	0	0	0	*	0	+	0	0	+	+	0	0	+								
ΣCarcinogenic PAHs	0	0	0	0	0	*	0	-	0	0	+	+	0	0	+	+							
TCEP	+	+	+	0	0	*	-	+	0	0	0	0	0	0	0	0	0						
TDCPP	+	+	+	+	0	*	-	+	0	0	0	+	0	+	0	+	+	+					
Bifenthrin	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0			
Cypermethrin	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*			
Lambda-cyhalothrin	0	0	0	0	-	*	0	+	+	0	+	+	0	0	+	+	+	0	0	*	*		
Fluoranthene	0	0	0	0	0	*	0	+	0	0	+	+	0	0	+	+	+	0	+	*	*	+	
Benzo(a)pyrene	0	0	0	0	0	*	0	+	0	0	+	+	0	0	+	+	+	0	0	*	*	+	+

Note: A positive sign (+) indicates a positive correlation existed, a negative sign (-) indicates a negative correlation existed, a zero (0) indicates no correlation existed, and an asterisk (*) indicates that a correlation could not be performed due to one or both of the two compared groups being composed entire of non-detects. ADP = antecedent dry period, EC = conductivity, SAR = soil adsorption ratio, TSS = total suspended solids, TCEP = tris(2-chloroethyl) phosphate, TDCPP = tris(1,3-dichloro-2-propyl) phosphate. Σ17PAHs includes naphthalene, 2-methyl naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene, and benzo(g,h,i)perylene. ΣCommonly Detected PAHs includes fluoranthene, pyrene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, and ideno(1,2,3-cd)pyrene. ΣCarcinogenic PAHs includes benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene.

Table 2-45. Correlation matrix based on Spearman’s Rho values ($\alpha = 0.05$) for the field sampling in OKC when combining results from the metal roof from all storm events that had samples collected from the metal roof.

	ADP	pH	EC	NO_3-N	SAR	B	Fe	Cu	Zn	Mn	TSS	Turbidity	Total Coliforms	*E. coli*	Σ17PAHs	ΣCommonly Detected PAHs	ΣCarcinogenic PAHs	TCEP	TDCPP	Bifenthrin	Cypermethrin	Lambda-cyhalothrin	Fluoranthene
ADP																							
pH	+																						
EC	+	+																					
NO_3-N	0	0	+																				
SAR	+	-	+	+																			
B	*	*	*	*	*																		
Fe	0	0	-	-	0	*																	
Cu	-	0	0	0	0	*	0																
Zn	0	-	0	0	0	*	0	0															
Mn	*	*	*	*	*	*	*	*	*														
TSS	+	+	+	0	0	*	0	0	0	*													
Turbidity	+	+	+	+	+	*	-	0	0	*	+												
Total Coliforms	0	0	-	0	0	*	0	0	0	*	0	0											
E. coli	0	0		0	0	*	0	0	0	*	0	0	-										
Σ17PAHs	0	+	+	0	0	*	0	0	0	*	+	+	0	0									
ΣCommonly Detected PAHs	0	+	+	0	0	*	0	0	0	*	+	+	0	0	+								
ΣCarcinogenic PAHs	0	+	+	0	0	*	0	0	0	*	+	+	0	0	+	+							
TCEP	0	0	0	0	0	*	0	0	-	*	0	0	0	0	0	0	0						
TDCPP	+	0	+	+	+	*	-	0	0	*	+	+	0	0	0	0	0	+					
Bifenthrin	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*				
Cypermethrin	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*			
Lambda-cyhalothrin	0	0	0	0	0	*	0	0	0	*	0	+	0	0	0	0	0	0	+	*	*		
Fluoranthene	0	+	0	0	0	*	0	0	0	*	+	+	0	0	+	+	+	0	0	*	*	0	
Benzo(a)pyrene	0	+	+	0	0	*	0	0	0	*	+	+	0	0	+	+	+	0	0	*	*	0	+

Note: A positive sign (+) indicates a positive correlation existed, a negative sign (-) indicates a negative correlation existed, a zero (0) indicates no correlation existed, and an asterisk (*) indicates that a correlation could not be performed due to one or both of the two compared groups being composed entire of non-detects. ADP = antecedent dry period, EC = conductivity, SAR = soil adsorption ratio, TSS = total suspended solids, TCEP = tris(2-chloroethyl) phosphate, TDCPP = tris(1,3-dichloro-2-propyl) phosphate. Σ17PAHs includes naphthalene, 2-methyl naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene, and benzo(g,h,i)perylene. ΣCommonly Detected PAHs includes fluoranthene, pyrene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, and ideno(1,2,3-cd)pyrene. ΣCarcinogenic PAHs includes benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene.

Table 2-46. Correlation matrix based on Spearman's Rho values ($\alpha = 0.05$) for the field sampling in OKC when combining results from the asphalt shingle roof from all storm events that had samples collected from the asphalt shingle roof.

	ADP	pH	EC	NO_3-N	SAR	B	Fe	Cu	Zn	Mn	TSS	Turbidity	Total Coliforms	*E. coli*	Σ17PAHs	ΣCommonly Detected PAHs	ΣCarcinogenic PAHs	TCEP	TDCPP	Bifenthrin	Cypermethrin	Lambda-cyhalothrin	Fluoranthene
ADP																							
pH	0																						
EC	0	+																					
NO_3-N	+	0	+																				
SAR	0	0	+	+																			
B	0	0	+	+	+																		
Fe	+	0	+	+	0	0																	
Cu	0	+	+	+	+	+	0																
Zn	+	0	+	+	+	+	+	+															
Mn		0	+	+	+	+	+	+	+														
TSS	+	0	+	0	0	0	+	0	+	0													
Turbidity	+	0	+	+	+	+	+	0	+	0	+												
Total Coliforms	0	0	0	0	0	0	0	0	0	0	0	0											
E. coli	0	0	0	0	0	0	0	0	0	0	0	0	0										
Σ17PAHs	0	0	+	+	+	+	0	+	0	+	+	+	0	0									
ΣCommonly Detected PAHs	0	0	+	0	0	0	0	+	0	+	+	+	0	0	+								
ΣCarcinogenic PAHs	0	0	+	0	0	0	0	0	0	0	+	+	0	0	+	+							
TCEP	+	0	+	+	+	+	+	0	+	+	+	0	0	0	0	0	0						
TDCPP	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
Bifenthrin	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*				
Cypermethrin	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*			
Lambda-cyhalothrin	+	0	0	0	0	0	0	0	0	0	+	+	0	0	0	0	0	0	0	*	*		
Fluoranthene	0	0	+	+	0	0	0	+	0	0	+	+	0	0	+	+	+	0	0	*	*	0	
Benzo(a)pyrene	0	0	+	0	0	0	0	+	0	+	+	+	0	0	+	+	+	0	0	*	*	0	+

Note: A positive sign (+) indicates a positive correlation existed, a negative sign (-) indicates a negative correlation existed, a zero (0) indicates no correlation existed, and an asterisk (*) indicates that a correlation could not be performed due to one or both of the two compared groups being composed entire of non-detects. ADP = antecedent dry period, EC = conductivity, SAR = soil adsorption ratio, TSS = total suspended solids, TCEP = tris(2-chloroethyl) phosphate, TDCPP = tris(1,3-dichloro-2-propyl) phosphate. Σ17PAHs includes naphthalene, 2-methyl naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene, and benzo(g,h,i)perylene. ΣCommonly Detected PAHs includes fluoranthene, pyrene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, and ideno(1,2,3-cd)pyrene. ΣCarcinogenic PAHs includes benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene.

2.4.4 Comparisons to Limits and Regulations

When comparing results to irrigation water-quality guidelines for Oklahoma, all discrete-samples were in either “good” or “excellent” categories for irrigation water quality, regardless of roofing material or runoff depth (Zhang 2013). Initial continuous EC concentrations were above the 750 μS/cm guideline for one storm event in OKC that had an ADP of 17 days, but quickly felt to “good” and “excellent” levels shortly thereafter.

Concentrations of PAHs and pyrethroid insecticides in runoff samples were compared to USGS Health-Based Screening Levels (HBSLs) to determine if runoff concentrations would be of potential concern for human health. Table 2-47 displays the HBSL concentrations available for comparison to the PAHs and pyrethroid insecticides and the maximum concentrations observed in the water samples. All detections were three orders of magnitude below the HBSL benchmark concentrations (Toccalino et al. 2012). Nevertheless, PAHs, PFRs, and pyrethroid insecticides were detected throughout the study at both sites. Significant differences ($\alpha = 0.05$) were observed to exist in concentrations of the organic compounds between sample times and roof type, indicating a first flush occurrence.

OKC samples had high concentrations of total coliform (90th percentile equal to 2311, 1652, and >2419 CFU/100 mL for the asphalt shingle, metal, and tar and gravel roof, respectively) and *E. coli* bacteria (90th percentile equal to 74, 1.1, and 396 CFU/100 mL for the asphalt shingle, metal, and tar and gravel roof, respectively). However, no trend could be identified between the presence of bacteria and roofing material or runoff depth. The highest concentrations of bacteria were observed in tar and gravel runoff, which can be attributed to the flatness of the roof and the accumulation of particulates and associated flora on them (Farreny et al. 2011). If the harvested rainwater was to be used as a potable source of water, disinfection would be required prior to use to meet USEPA regulations and WHO recommendations.

Table 2-47. Health-based screening levels (HBSL) and comparisons to concentrations observed in roof runoff samples from the simulation and field sampling (OKC) studies. NAV = data not available.

Chemical name	**HBSL (ng/L)**	**Max Value in Simulation Samples (ng/L)**	**Max Value in OKC Samples (ng/L)**
Naphthalene	100,000	143	147
2-Methylnaphthalene	30,000	81	62
Acenaphthylene	NAV	<30	<30
Acenaphthene	400,000	37	<30
Fluorene	300,000	55	<30
Phenanthrene	NAV	90	141
Anthracene	2,000,000	<15	77
Fluoranthene	300,000	232	255
Pyrene	200,000	167	206
Benz[a]anthracene	NAV	69	116
Chrysene	NAV	192	149
Benzo[b]fluoranthene	NAV	173	209
Benzo[k]fluoranthene	NAV	116	61
Benzo[a]pyrene	NAV (200*)	118	104
Indeno[1,2,3-cd]pyrene	NAV	149	170
Dibenz[a,h]anthracene	NAV	12	26
Benzo[ghi]perylene	NAV	86	109
Tri(2-chloroethyl)phosphate	NAV	43	126
Tris(dichlorisopropyl)phosphate	NAV	215	57
Bifenthrin	9,000	43	<10
Cypermethrin	40,000	<90	<90
Cyhalothrin	7,000	<10	117

*USEPA Maximum Contaminant Level

2.5 Summary and Conclusions

Significant differences ($\alpha = 0.05$) between sequential samples were observed for nearly all parameters and constituents analyzed in the rainfall simulation (SIM) samples, indicating the presence of a first flush. While it was difficult to distinguish significant differences based on runoff depths, there were significant differences in water quality based on roof type at the OKC site ($\alpha = 0.05$). Particulate concentrations (i.e. TSS and PAHs) in SIM runoff were significantly different ($\alpha = 0.05$) based on simulation intensity. There was no significant difference ($\alpha = 0.05$) in runoff water quality between NS and EW oriented roofs used in the rainfall simulation study. In the simulations events, the metal roofs had higher initial PAH concentrations while the asphalt shingle roofs had longer retention times of PAHs in the runoff. This can be contributed to the rougher surface area of the asphalt shingles compared to the metal sheeting.

Roof runoff did not exceed irrigation water-quality guidelines in any of the SIM or OKC samples. High total coliform and *E. coli* concentrations were observed in runoff samples; however, no correlation could be found between occurrence and roof type or runoff depth. Positive correlations were observed between EC, TSS, turbidity, and PAH concentrations in the rooftop runoff.

While present at trace levels (ng/L), concentrations never exceeded Health Based Screening Levels for the PAH compounds. PAHs were observed in up to 42% of SIM samples and up to 84% of all OKC samples. The 90th percentile of ∑17PAHs for SIM samples were 735, 559, and 497 ng/L for asphalt shingle, metal, and clay tile roofs, respectively. The 90th percentile of ∑17PAHs for OKC field samples were 1440, 517, and 391 ng/L for asphalt shingle, metal, and tar and gravel roofs, respectively. TCEP and TDCPP were in 3% and 27% of SIM samples, respectively, and 23% of OKC samples. Lambda-cyhalothrin was undetected in SIM samples and detected in 7% of OKC samples. Bifenthrin was detected in <1% of SIM samples and undetected in OKC samples. Cypermethrin was not detected in either SIM or OKC samples. Atmospheric deposition was observed to be the main contributor of pollutants in the roof runoff.

CHAPTER 3

FIRST-FLUSH DIVERSIONS FOR ROOF-BASED RAINWATER HARVESTING

3.1 Abstract

The majority of a rooftop's dust and debris are believed to be washed away during the initial periods of a rainfall event, a phenomenon known as the "first flush". In order to improve the water quality of harvested rainwater, many researchers have called for the diversion of the first flush to be included in the design of the collection system. Diverting the first flush can greatly improve the overall quality of the harvested rainwater. The main objective of this study was to use roof- runoff water-quality results from simulated and actual storm events to quantify a first-flush diversion based on the mass removal of total suspended solids (TSS) and polycyclic aromatic hydrocarbons (PAHs). An analysis was also performed on continuous conductivity (EC) measurements observed in roof runoff during storm events. Lastly, a pilot study was conducted in order to determine if PAHs had the potential for long-term accumulation in soils watered with roof runoff that had no first-flush diversion.

Two separate first-flush effects were discovered to occur in roof runoff between TSS and PAH concentrations, with the PAHs showing a faster rate of removal than TSS. First-flush recommendations are provided based on the 50, 75, 90, and 95% mass removals of TSS and PAHs for asphalt shingle, metal, clay tile, and tar and gravel roof runoff. When neglecting the tar and gravel roof due to its poor catchment efficiency, the clay tile roofs required the smallest first-flush

diversions to remove the majority of TSS and PAHs when compared to results from the asphalt shingle and metal roofs. The 0.41 – 0.82 mm first-flush diversion recommended by the Texas Water Development Board was observed to, at best, remove up to 50% of PAHs for clay tile and metal roofs in this study. Results from this study indicate a much higher diversion is needed in order to remove at least 50% of TSS or PAHs from asphalt shingle and metal roof runoff. Diverting a first-flush based on TSS removal has the potential to remove the majority of PAHs in roof runoff; however, it can also lead to excessive waste of harvested rainwater if too much is diverted Diverting a first-flush based on EC measurements has the potential to also remove the majority of PAHs in the roof runoff. Designing first-flush diverters with sensors measuring EC can automate the first-flush diversion process and make the diverters applicable to more than just one site-specific location.

Approximately 70% of the paired soil samples from the pilot study on PAH accumulations in soils had higher PAH concentrations in soils that received roof runoff compared to soils that did not. These results indicate that there is a potential for long-term accumulation of PAHs in soils that are watered with roof runoff that has no first-flush diversion. PAH concentrations observed in the soils were compared to regional screening levels for individual PAH compounds in residential soils compiled by the USEPA to determine potential human-health risks associated with the levels of contamination. The soil samples that received roof runoff exceeded the minimum screening level concentrations 24 – 100% of the time (n = 17). Further research is recommended on the effects PAH concentrations in soils have on plants and vegetables, as one potential end use of harvested rainwater is irrigation for small gardens.

3.2 Introduction

3.2.1 Rainwater Harvesting and the First-Flush Effect

Rainwater harvesting (RWH) is a low impact development stormwater best management practice that involves the capture, diversion and storage of rainwater while also helping reduce stormwater runoff volume. Roof-based rainwater harvesting is implemented in both developed and developing countries for non-potable and potable use. However, the water quality of the harvested rainwater is of great concern and many studies have been performed on this topic, as highlighted in Chapter 2. In order to improve the water quality of harvested rainwater, many researchers have called for the diversion of the "first flush" to be included in a RWH collection system (Mendez et al. 2011, Doyle and Shanahan 2012, Martinson and Thomas 2005, Förster 1999).

The majority of a rooftop's dust and debris are believed to be washed away during the initial periods of a rainfall event, a phenomenon known as the first flush (Martinson and Thomas 2005, Zhang et al. 2010). The idea of a first flush originated in urban stormwater and sewage research, but has since been applied to rainwater harvesting (Sansalone and Cristina 2004, Doyle and Shanahan 2012, Kus et al. 2010). From studies based on stormwater discharges, Schriewer et al. (2008) summarized that some researchers claim the first flush occurs when at least 80% of the pollution load is transferred in the first 30% of runoff volume whereas others suggest it occurs when most of the total pollution load is in the first 25% of runoff. The first flush can be defined based on either a concentration or on a mass-basis (Sansalone and Cristina 2004).

Studies have shown that the majority of pollutants in urban runoff are in particulate form (Zhang et al. 2010, Göbel et al. 2007). In a watershed study, a first-flush effect was observed in the occurrence of polycyclic aromatic hydrocarbons (PAHs), where 30 to 60% of the total PAH load was discharged in the first 20% of the storm volume (Stein et al. 2006). Rule et al. (2006) observed a first-flush effect for PAHs in urban wastewater catchments and contributed it to a long antecedent dry period. Metal and total suspended solid (TSS) concentrations from asphalt and concrete boards located near parking lots decreased to <15% of initial concentrations within 10-20 minutes of a simulated storm after the boards experienced 7 days of natural atmospheric deposition

(Wicke et al. 2012). First-flush effects of zinc concentrations were observed in 93% of runoff events from a 14 year-old zinc roof (Schriewer et al. 2008). While Kus et al. (2010) observed TSS levels to be below Australian Drinking Water Guidelines (ADWG), they also reported that bypassing the first flush of TSS improves the water stored in the collection tank by reducing TSS during a filtration process.

Diverting the first flush can greatly improve the overall quality of the harvested rainwater (Lye 2009, Doyle and Shanahan 2012, Kus et al. 2010, Meera and Ahammed 2006). There is no universal consensus on what exactly constitutes a first flush for roof-based RWH (Lye 2009, Martinson and Thomas 2005). This is due to the many variables that play a role in the water quality of roof runoff. Roofing material, catchment parameters, precipitation events, antecedent dry period, local weather, chemical properties of the pollutants, abundance of wildlife, and geographical location of the RWH system all need to be taken into consideration when designing a first flush device (Förster 1999, Förster 1996, Doyle and Shanahan 2012). It is important to note that while the diverting the first flush is important, care must be taken not to divert too much and waste clean water (Doyle and Shanahan 2012).

Research has shown varied conclusions in how much runoff should be diverted in the first flush in order to have satisfactory water quality in the RWH system. Yaziz et al. (1989) suggested diverting 0.33 mm for galvanized-iron and concrete tile roofs. Martinson and Thomas (2005) proposed that contamination will be halved for each mm of rainfall that is diverted from the RWH system. The Texas Water Development Board (TWDB) (2005) recommends diverting 38 liters for every 93 m^2 of catchment area (0.41 mm). Mendez et al. (2011) observed significantly higher concentrations of conductivity (EC), total coliform, fecal coliform, turbidity, TSS, nitrate, nitrite, and metal concentrations within a first-flush diversion of 0.41 mm compared to water harvested after the first flush. For a site-specific diversion in Bisate, Rwanda, it was observed that diverting the first 1 mm of runoff would lower *Escherichia coli* concentrations to 10 colony-forming units/100 mL and reduce turbidity from 100 NTU to less than 40 NTU (Doyle and Shanahan 2012). Table 3-1 provides a summary of first-flush diversion recommendations from the literature for roof-based rainwater harvesting.

Many health concerns arise when using untreated harvested rainwater as drinking water due to possible microbial and chemical contamination (de Kwaadsteniet et al. 2013, Meera and Ahammed 2006). In the developing world, rainwater harvesting is used for both potable and non-potable purposes (de Kwaadsteniet et al. 2013, Meera and Ahammed 2006). With the wide-spread practice of open burning in these countries, numerous contaminants, including PAHs, are released into the atmosphere that can, in turn, be atmospherically deposited onto rooftops (Estrellan and Iino 2010, Gogra et al. 2010, Zhang et al. 2011). PAHs have a tendency to adhere to particles and have been observed to have strong affiliations with TSS in stormwater runoff (DiBlasi et al. 2008). Therefore, first-flush diversions based on TSS removal can also potentially remove PAHs found in roof runoff. As this research has shown a positive correlation between PAHs and TSS in roof runoff (Tables 2-24 to 2-30 and 2-43 to 2-46), focusing on a first flush diversion based on TSS removal has the potential to greatly reduce PAH concentrations in harvested roof runoff.

Table 3-1. First-flush diversion recommendations from the literature for roof-based rainwater harvesting. Adapted from Doyle and Shanahan (2012).

Reference	Amount to be Diverted	Notes	Criteria Diversion Based on
Pacey and Cullis (1986)	First 10-20 min. of storm	Author recommendation	Removing dust and leaves after a long dry period
Michaelides (1986)	0.3 – 3.0 mm First 5-20 min. of storm	Range of diversions observed from other research; does not give one recommendation	-
Yaziz et al. (1989)	0.33 mm	-	Fecal and total coliforms
Ntale and Moses (2003)	0.83 mm or first 10 min	Should be decreased in rainy season	-
TWDB (2005)	0.41 - 0.82 mm	Depending on dry days, debris, trees, and season	Review of other research
Martinson and Thomas (2005)	Contaminant load will halve for each mm	-	Turbidity
Rainwater Harvesting Pty. Ltd (2010)	0.50 mm 2.0 mm	Low pollution (clean environment) High pollution	Open field, no trees, no bird droppings Leaves and debris, bird droppings, various animal matter (i.e. insects, skinks)
(Kus et al. 2010)	2.0 mm	Recommended for Australia	Australian Drinking Water Guidelines, rainwater organic matter
Doyle and Shanahan (2012)	1.0 mm	Recommended for Bisate, Rwanda	*E. coli* concentrations and turbidity

3.2.2 Polycyclic Aromatic Hydrocarbons

PAHs are ubiquitous, hydrophobic compounds that can sorb onto particulates and be transported by water on suspended sediment or through the air on dust particles (Van Metre et al. 2000). PAHs are of environmental concern due to their detrimental biological effects, toxicity, mutagenicity, carcinogenicity, and their bioaccumulation potential (Haritash and Kaushik 2009). Research has shown earthworms, zucchini, cucumber, and squash to accumulate PAHs from contaminated soil (Parrish et al. 2006). Maliszewska-Kordybach and Smreczak (2000) conducted a study evaluating the effects of varying concentrations of fluorene, anthracene, pyrene, and chrysene in soils on wheat, oat, maize, tomato, bean, and sunflower growth. While the researchers observed that soils contaminated with <10 mg/kg PAHs actually stimulated plant growth at early stages of development, PAHs were observed to significantly inhibit tomato growth in sandy soil at as low as 20 mg/kg of soil (Maliszewska-Kordybach and Smreczak 2000). In a study by Eom et al. (2007), soils samples from a former cokery site were analyzed for the presence of the 16 USEPA priority PAHs were observed to have a total concentration of 2634 ±241 ng/kg dry weight. These concentrations were observed to have severe effects on the reproduction of the collembolae *Folsomia candida* and the earthworm *Eisenia fetida* when evaluating cocoon and juvenile production, respectively (Eom et al. 2007).

PAHs have been observed in urban runoff, including rooftop runoff, as has been demonstrated in the literature and in this research (Chapter 2). As harvested rainwater may be used for irrigation purposes, it is important to evaluate any potential human-health risks that may arise from long-term accumulation of PAHs in soils due to concentrations in roof runoff.

3.2.3 Objectives

The objectives of this study were to (1) use roof runoff water quality results from simulated and actual storm events to quantify a first-flush diversion based on mass removals of TSS and

PAHs; (2) evaluate a first-flush occurrence in roof runoff based on continuous EC measurements throughout a storm event; and (3) perform a pilot-study to determine in PAHs have the potential for long-term accumulation in soils receiving roof runoff that has no first-flush diversion.

3.3 Materials and Methods

3.3.1 Roof-Runoff Sampling

The study was conducted at two sites in Oklahoma: at the Oklahoma State University (OSU) Agronomy Farm in Stillwater and the OSU Oklahoma City campus (OKC). The Agronomy Farm was located approximately 300 meters north of Highway 51, right on the edge of town, and the OKC site was located approximately 200 meters west of Interstate 44 (I – 44), in the middle of the city. Simulated rainfall events (SIM) were performed at the Agronomy Farm, while field samples were collected from actual events at OKC.

Eighteen simulated roof structures (1.67 m^2 catchment area) were constructed and placed at the Agronomy Farm in June 2011. New Elite Glass-Seal® three tab asphalt shingles (Tamko®, Joplin, MO), new MasterRib® acrylic coated Galvalume Plus® metal sheeting (Severstal Sparrows Point, LLC, Sparrows Point, MD), and 60 year-old clay tile (Reddick Roofing and Guttering, Enid, OK) roofing materials were installed on the structures and replicated six times each. Nine roofs, consisting of three replicates of each roofing material, were oriented north-south while the remaining nine roofs were oriented east-west. A portable rainfall simulator was constructed to simulate high (64 mm/hr), medium (38 mm/hr), and low (28 mm/hr) intensity storm events on the roofs. Six discrete samples were manually and sequentially collected from each roof during the three simulated rainfall events.

Two full-scale commercial and one constructed roof were sampled at OKC: a 29-year-old flat tar and gravel roof, an eight-year-old metal roof, and an approximately one-year old asphalt shingle roof. The roofs had contributing catchment areas of 92, 88, and 9.3 m^2, respectively. The asphalt shingle roof was constructed on site strictly for research purposes and placed near the tar and gravel roof. The metal roof was located within 100 m of the tar and gravel and asphalt shingle roofs; the tar and gravel roof was approximately 17 m from the asphalt shingle roof. Portable samplers (6712, Teledyne Isco, Lincoln, NE) were used to collect twelve paired, one-liter samples from each storm event, with the majority of samples collected during the beginning of the storm. Samples were collected from 11 storm events between April and July 2012. Further details on sampling procedures and analysis can be found in Chapter 2.

All samples from the study were analyzed for the following: pH, EC, TSS, turbidity, nitrate-nitrogen, boron, sodium-adsorption ratio, iron (Fe), copper (Cu), zinc (Zn), and manganese (Mn). Samples were also analyzed for the presence of seventeen PAHs (naphthalene, 2-methyl naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene, and benzo(g,h,i)perylene); phosphorus flame retardants (PFRs) tris(2-chloroethyl) phosphate (TCEP), tris(1,3-dichloro-2-propyl) phosphate (TDCPP); and pyrethroid insecticides bifenthrin, cypermethrin, and lambda-cyhalothrin using solid-phase extraction (SPE) coupled with gas chromatography-mass spectrometry.

3.3.2 Percent Mass Removals

The total mass removals of 50, 75, 90, and 95% were used to calculate the percent volume diversions required for a given mass removal. This was performed for TSS, ΣCarcinogenic PAHs, ΣCommonly Detected PAHs, and the PAHs fluoranthene and benzo(a)pyrene for samples collected at both the SIM and OKC sites. The ΣCommonly Detected PAHs included fluoranthene, pyrene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, and ideno(1,2,3-cd)pyrene. The ΣCarcinogenic PAHs included benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene.

The percent removal volume results were then converted into runoff depth diversions (mm) for each roof. Six samples were collected from each SIM roof during each simulation event; however, samples four and five were not analyzed for PAHs, PFRs, or pyrethroid insecticides. For the percent mass removal calculations, PAH concentrations were interpolated for sample four based on concentrations observed in samples two and three; sample five concentrations were interpolated based on concentrations observed in samples three and four. Concentrations from sample six were not used for interpolations due to the difference in volume; samples one through five were each 2 L in volume whereas sample six varied between 8.1 and 23 L, depending on roof type and simulation intensity. All individual detections of PAHs were added together based on category (i.e. Total, Commonly Detected, Carcinogenic), and the summed data were used in the percent removal calculations, regardless if the summed concentrations were less than the summed reporting limits (RL) of the summed data.

3.3.3 Polycyclic Aromatic Hydrocarbon Accumulation in Soils

A pilot study was conducted in order to determine if PAHs had the potential for long-term accumulation in soils that were irrigated with roof runoff that did not contain a first-flush diversion. Soils located directly underneath and away from roof downspouts were sampled and concentrations between the paired samples were compared for the presence of PAH compounds. If PAHs were observed in higher concentrations in the soils that directly received roof runoff (i.e. soils beneath downspouts) compared to soils that did not receive roof runoff, it would indicate a potential for PAH accumulation. Concentrations were compared to risk-based screening levels of polycyclic aromatic hydrocarbons for residential soils in order to determine if the soil concentrations could pose a human-health risk.

Approximately 200 g soil samples were taken from beneath each downspout from a 0.1 m^2 area, with a paired sample taken in an area nearby that did not receive downspout drainage. Samples were taken from the first 3 cm of topsoil beneath downspouts for asphalt shingle, metal, and flat tar & gravel buildings in Oklahoma City (OKC) and Stillwater (STW). Seventeen paired soil samples were analyzed for the presence of the 17 PAHs, as well as for TCEP, TDCPP, bifenthrin, cypermethrin, and lambda-cyhalothrin. Samples were stored frozen at -20°C until extractions took place.

Each soil sample was thawed and well mixed prior to removing 1.5 g of soil for the sample. Extraction of the organic contaminants of interest followed methods outlined by Morrison et al. (2013) for extracting fungicides in sediment samples. Each sampled received 100 µL of p-Terphenyl as a surrogate in two 50 µL increments in order to fully saturate the soil. A mortar and pestle were used to mix the soil with 750 mg of diatomaceous earth, 900 mg of Florisil, and 50 mg of primary secondary amine-bounded silica. A column was constructed using a hollow solid-phase extraction tube filled with 500 mg of activated silica gel, followed by 1.0 g of sodium sulfate, then the soil mixture on top. The column was then eluted with 15 mL of hexane:ethyl ether (1:2, v/v) into test tubes. The eluate was then evaporated down to 0.5 mL and analyzed by GC-MS. The average percent recovery of p-Terphenyl in soil samples was 89.8% (±14.6).

In addition to the soil sampling, an accumulation model was created to estimate the average PAH concentrations in the roof runoff from the 17 buildings based on the concentrations observed in the soils. It was problematic estimating the exact contributing area of each roof to a single downspout without physically inspecting the roof surface; this was particularly true for the flat roofs. Therefore, using an industrial “rule of thumb” for sizing downspouts, and including a safety factor, it was estimated that a single downspout can handle approximately 1.2 m^2 of catchment area/cm^2 of downspout cross-sectional area (Steadman n.d.). The annual runoff volume that drained through a single downspout, Q_D, was then estimated by,

$$Q_D = A_D \times 1.2 \frac{m^2}{cm^2} \times C_r \times R \tag{3-1}$$

where A_D is the area of the downspout (cm^2), $1.2 \frac{m^2}{cm^2}$ refers to the catchment area the downspout is estimated to serve, C_r is the roof's runoff coefficient, and R is the annual rainfall amount (mm). It was assumed that each downspout drained the runoff into a 0.1 m^2 area, to a depth of 3 cm. Assuming a soil density of 1.5 g/cm^3 and a representative volume of 0.003 m^3, it was estimated that the roof runoff drained into approximately 4.5 kg of soil.

The transport potential of PAHs from the runoff water to the soil was quantified directly by calculation of the retardation, *R*, which is the ratio of the seepage rate of the water versus the speed of the compound, using the following equation (Ramaswami et al. 2005),

$$R = 1 + \frac{\rho_b}{\theta} f_{oc} K_{oc} \tag{3-2}$$

where ρ_b is the soil dry bulk density, θ is the soil water content, and f_{oc} is the soil organic content. Neglecting uptake, the PAH mass balance in the soil was quantified as,

$$\frac{\partial M}{\partial t} = C_o Q - M \frac{\ln(2)}{\lambda} \tag{3-3}$$

where t is time, M is the total mass of PAH, C_o is the concentration of the PAH in the runoff, Q is the annual volume of runoff, and λ is the half-life of the PAH compound. The first term on the right hand side is the applied mass and the second is the degradation. The solution to this relation is,

$$M(t) = \frac{\lambda C_o Q}{\ln(2)} \left[1 - e^{-\frac{\ln(2) t}{\lambda}}\right] \tag{3-4}$$

The accumulation of PAHs in the soil was based on the time, t (years), between when the roof was initially constructed and the year the soil samples were taken (2012). The estimated soil PAH concentrations were calculated by dividing the mass accumulation at time t by the assumed mass of the soil receiving the roof runoff; 4.5 kg. Estimations of C_o were made in the model until the expected PAH concentrations in the soil at time *t* matched the measured concentrations from the pilot study.

3.3.4 Continuous Conductivity Monitoring

Hydrolab MS5 Water Quality Multiprobes (sondes) (Hach®, Loveland, CO) were used to record continuous data on the EC, turbidity, and temperature of the roof runoff passing through the downspouts at the OKC site. A single downspout on both the tar and gravel and metal roofs were replaced and modified with a PVC pipe configuration in order to allow for continuous water quality readings and sampling, as shown in Figures 3-1 and 3-2. A smaller yet identical PVC downspout configuration was placed on the asphalt shingle roof (Figure 3-3). The new downspout was designed to (1) store water in-between storm events to keep a water-quality sonde wet and (2) allow for sampling of roof runoff. The sondes were installed in the extension of a 45° PVC wye in the downspouts. The sondes were calibrated in the field before each event using a two-point calibration curve for turbidity readings with 100 NTU and 1000 NTU standards and calibrated for EC using a 1413 µS/cm standard. Only EC results were deemed usable at the end of the study; the turbidity readings had numerous interferences with readings due to air bubbles created when runoff entered the downspouts.

Figure 3-1. Modified downspout configuration for the OKC metal roof.

Figure 3-2. Modified downspout configuration for the OKC tar and gravel roof.

Figure 3-3. Modified downspout configuration for the OKC asphalt shingle roof.

In order to account for mixing between the stored downspout water and incoming rainfall runoff, a rhodamine tracer study was conducted on the larger downspout configurations prior to the field study. A known rhodamine dye concentration mixture was constantly injected into the downspout using a peristaltic pump. Samples were taken every 30 seconds in order to see how long it took the water in the downspout to become completely mixed with the incoming mixture. Three flow rates were tested and a regression equation was created from the data,

$$X = \left(\frac{EC_{downspout}}{102.71}\right)^{\frac{1}{0.1508}} \tag{3-5}$$

where $EC_{downspout}$ is the EC of the water already in the downspout and X is the fraction of the downspout water with the given EC. Using the fraction calculated from the regression equation, the EC of the incoming rainwater was determined based on its mixing with the downspout water that was present before the storm. The EC of the rainfall runoff was calculated by,

$$EC_{rain} = \frac{EC_{downspout} - X(EC_{downspout\ initial})}{(1-X)} \tag{3-6}$$

3.4 Results and Discussions

3.4.1 Percent Mass Removals

When evaluating a first flush based on percent mass removals of TSS and PAHs in roof runoff, it was discovered that the PAHs were removed at a faster rate than TSS. Boxplots in Figures 3-4 through 3-13 show the interquartile range of diversions required for 50, 75, 90, and 95% of mass removals of TSS and PAHs for SIM and OKC samples. The geometric mean of these data are given in Table 3-2.

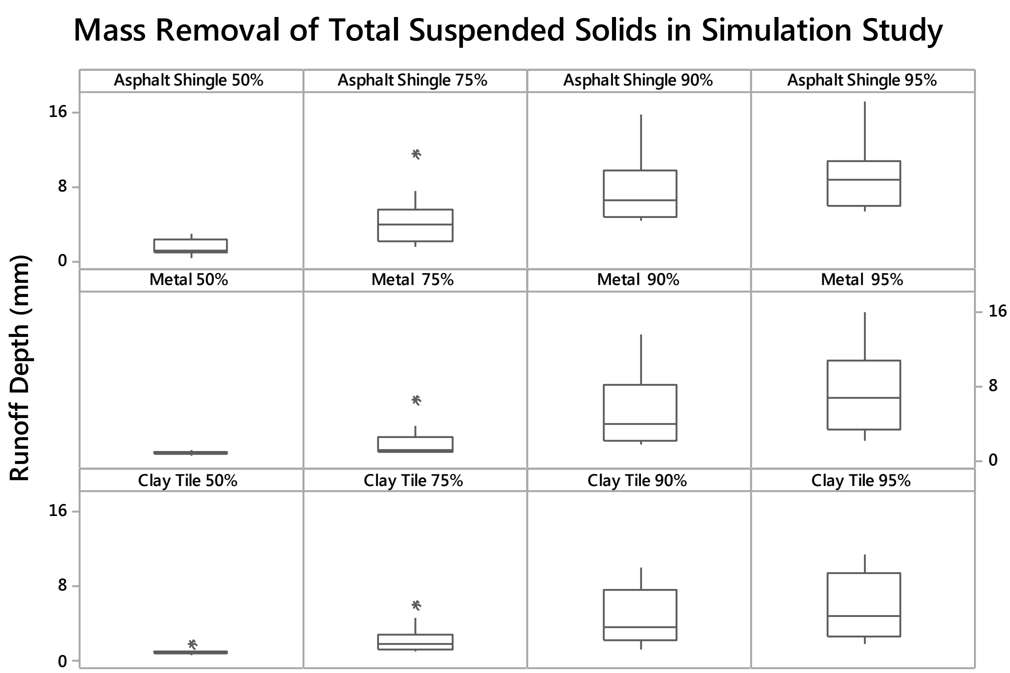

Figure 3-4. Diversions required to remove total suspended solids in samples from the simulated rainfall events based on a 50, 75, 90, and 95 percent mass removals.

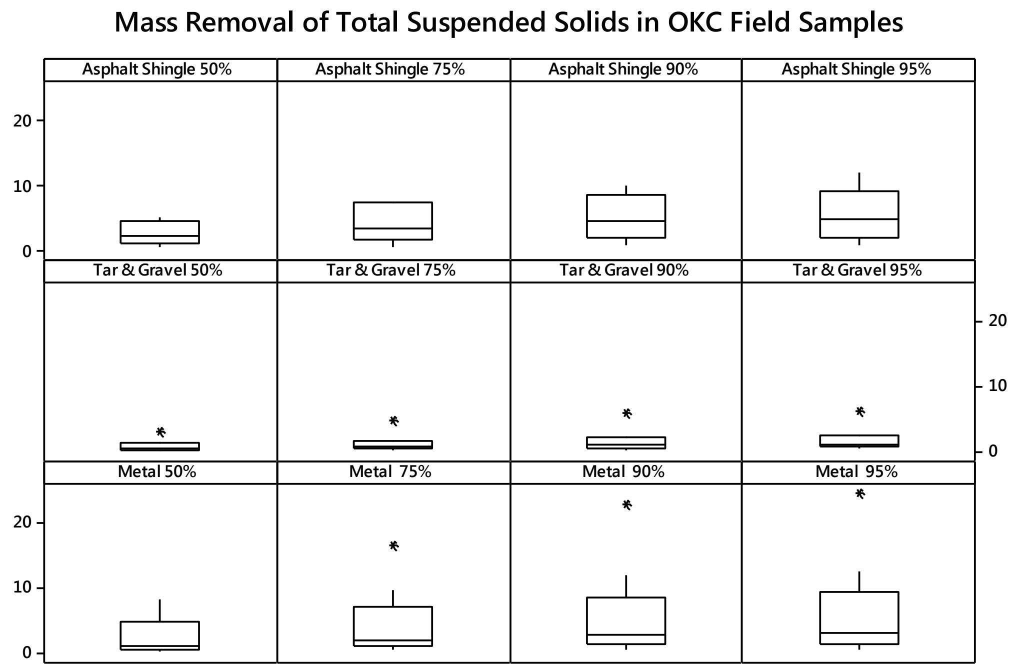

Figure 3-5. Diversions required to remove total suspended solids in samples from the OKC field samples based on a 50, 75, 90, and 95 percent mass removals.

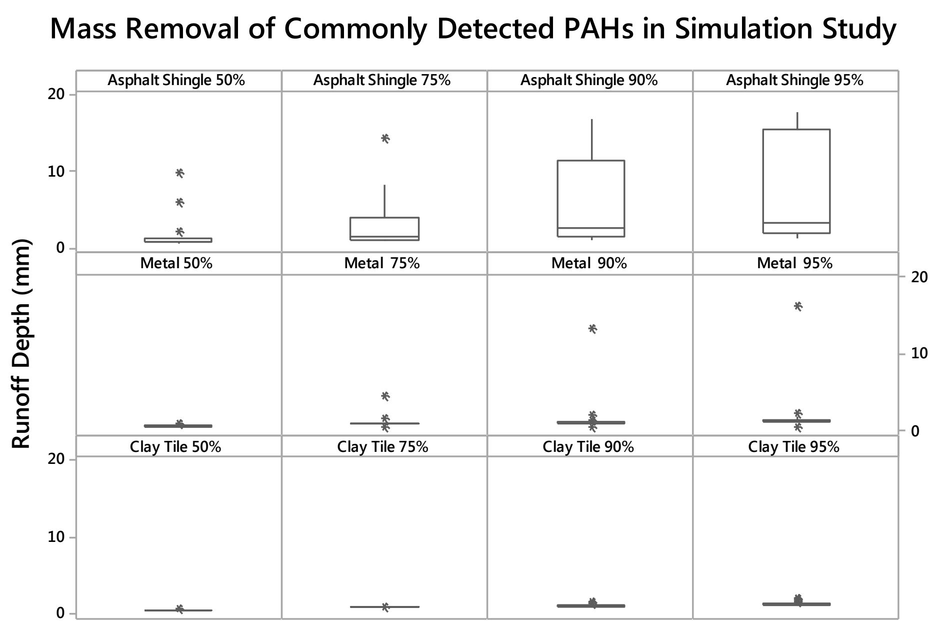

Figure 3-6. Diversions required to remove ∑Commonly Detected PAHs in samples from the simulated rainfall events based on a 50, 75, 90, and 95 percent mass removals.

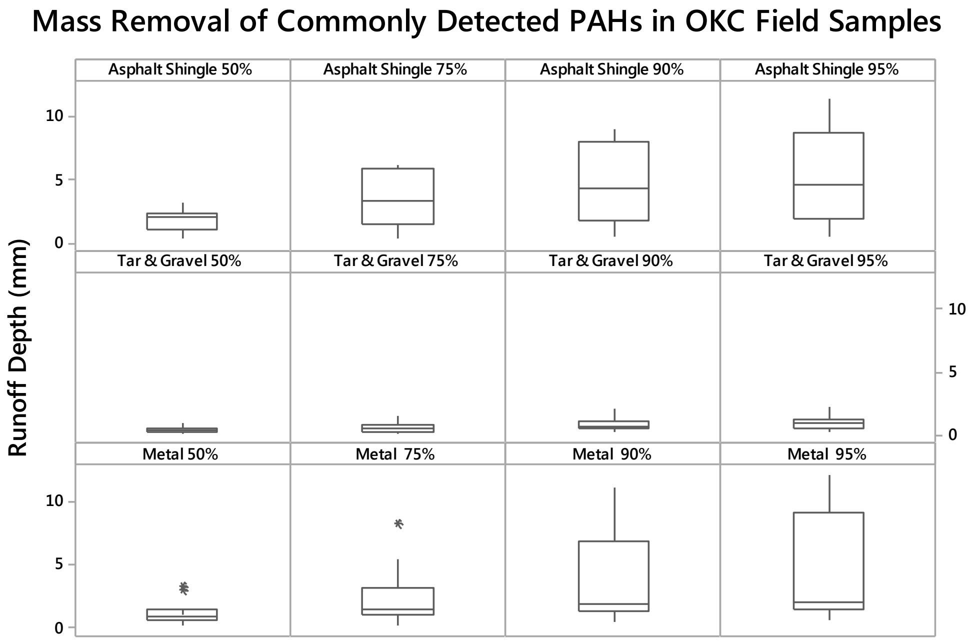

Figure 3-7. Diversions required to remove ∑Commonly Detected PAHs in samples from the OKC field samples based on a 50, 75, 90, and 95 percent mass removals.

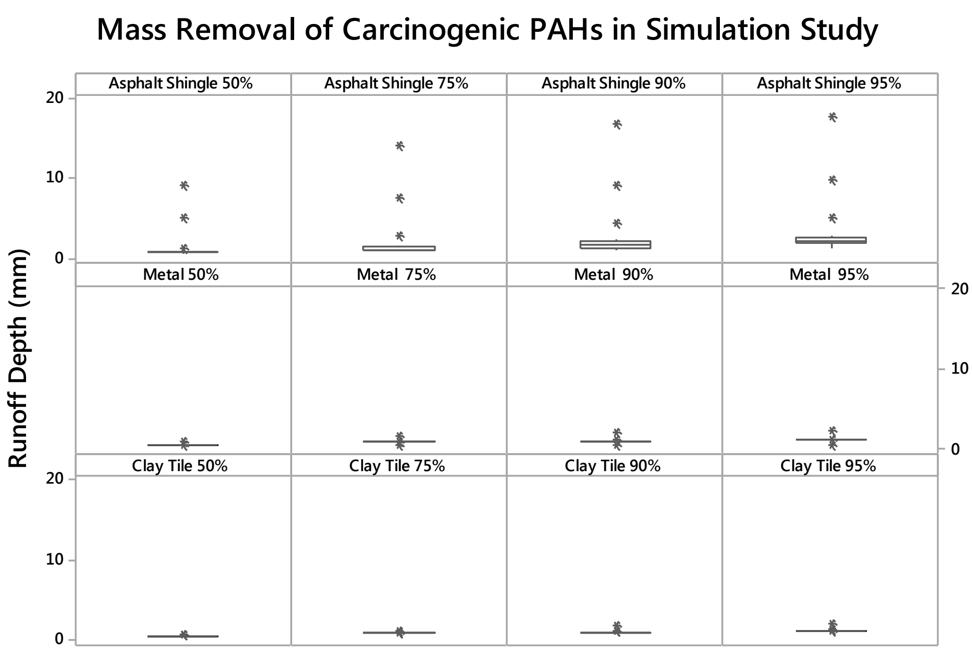

Figure 3-8. Diversions required to remove ∑Carcinogenic PAHs in samples from the simulated rainfall events based on a 50, 75, 90, and 95 percent mass removals.

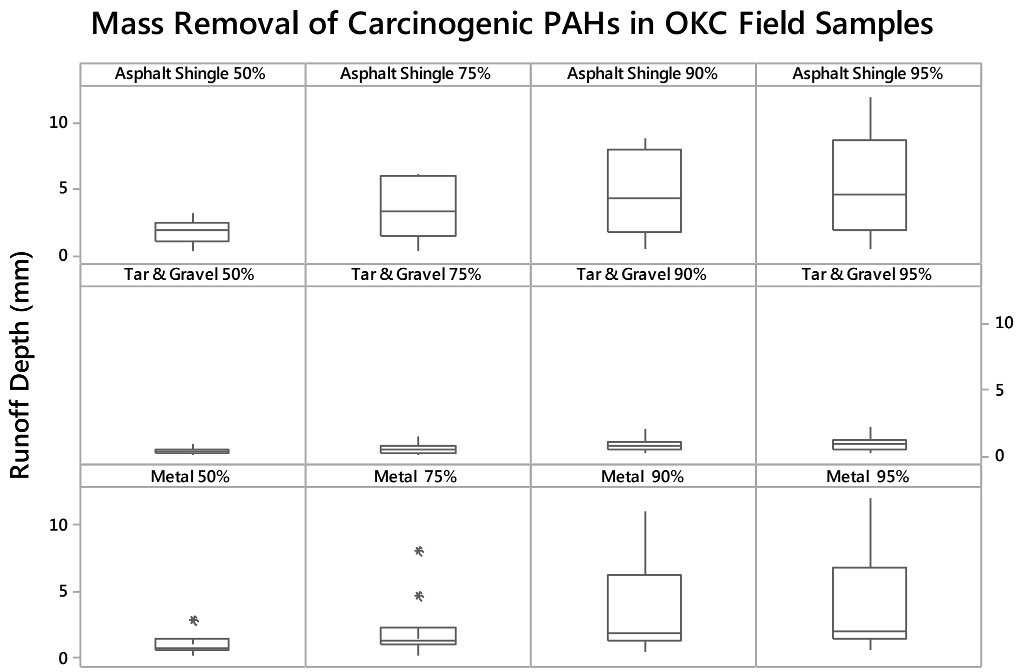

Figure 3-9. Diversions required to remove ∑Carcinogenic PAHs in samples from the OKC field samples based on a 50, 75, 90, and 95 percent mass removals.

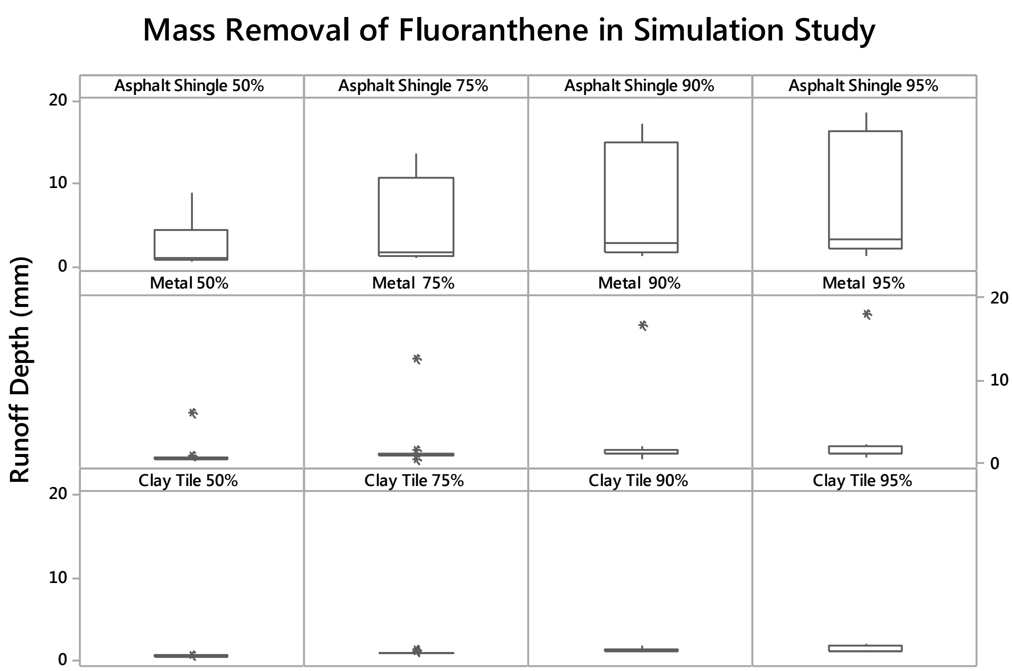

Figure 3-10. Diversions required to remove fluoranthene in samples from the simulated rainfall events based on a 50, 75, 90, and 95 percent mass removals.

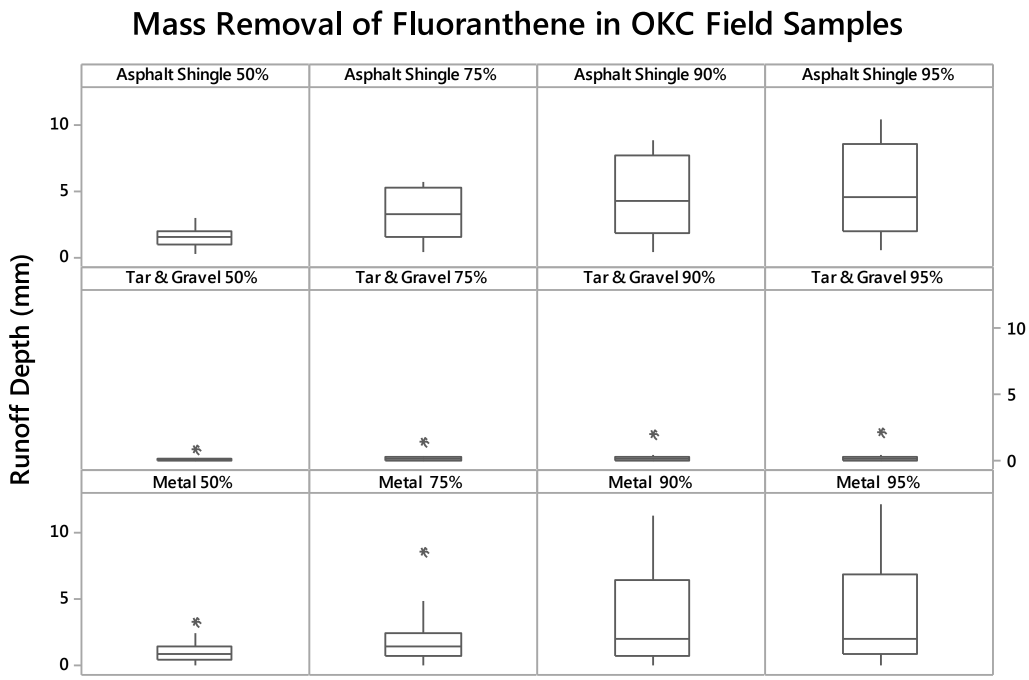

Figure 3-11. Diversions required to remove fluoranthene in samples from the OKC field samples based on a 50, 75, 90, and 95 percent mass removals.

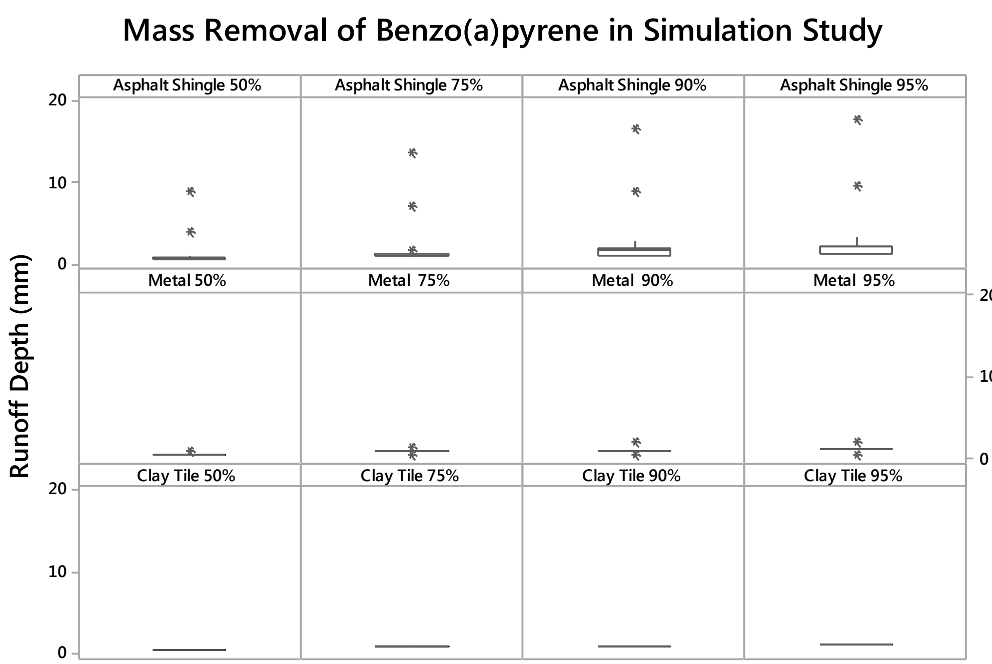

Figure 3-12. Diversions required to remove benzo(a)pyrene in samples from the simulated rainfall events based on a 50, 75, 90, and 95 percent mass removals.

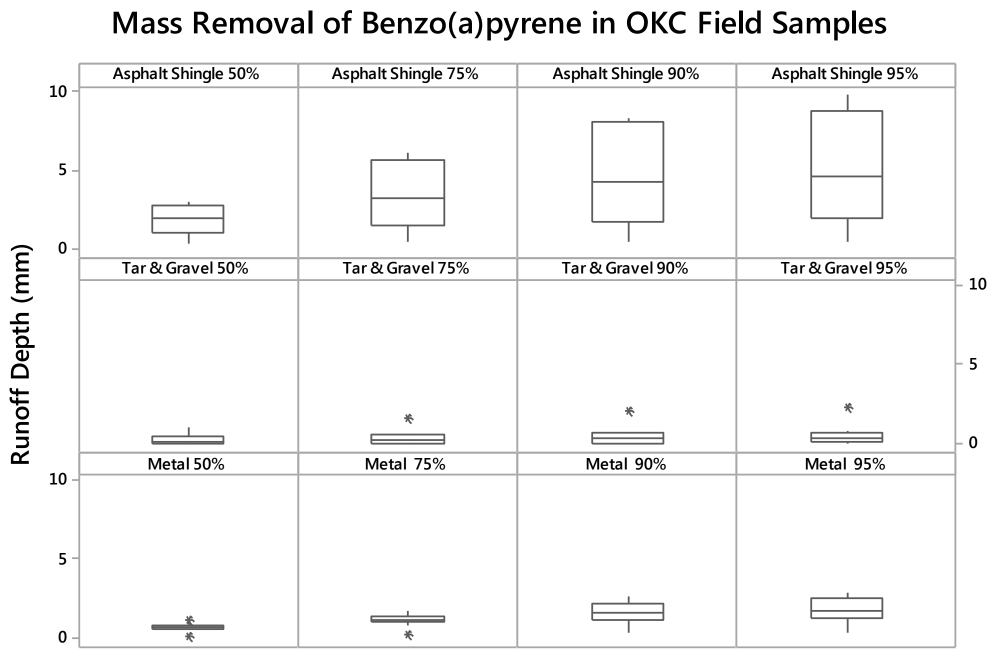

Figure 3-13. Diversions required to remove benzo(a)pyrene in samples from the OKC field samples based on a 50, 75, 90, and 95 percent mass removals.

Table 3-2. Roof runoff depth first-flush diversions (mm) required for percent mass removals for SIM and OKC roofs. Geometric Mean (±Standard Deviation).

	Asphalt Shingle (SIM)				Metal (SIM)				Clay Tile (SIM)			
	50%	**75%**	**90%**	**95%**	**50%**	**75%**	**90%**	**95%**	**50%**	**75%**	**90%**	**95%**
TSS												
38	1.3 (1.0)	4.8 (3.2)	8.3 (4.2)	10 (4.4)	0.9 (0.2)	2.2 (2.1)	5.5 (4.1)	8.2 (4.9)	1.0 (0.4)	2.8 (1.8)	5.0 (3.2)	6.0 (3.7)
28	1.1 (0.8)	2.8 (2.3)	6.0 (2.5)	7.6 (2.3)	0.8 (0.1)	1.4 (0.6)	3.2 (3.1)	4.3 (3.6)	0.9 (0.2)	1.6 (0.7)	2.9 (2.4)	4.1 (3.2)
∑Commonly Detected PAHs												
64	1.1 (0.5)	3.2 (2.6)	9.0 (4.4)	11 (5.3)	0.7 (0.1)	1.1 (1.6)	1.5 (5.1)	1.8 (6.2)	0.6 (0.03)	0.9 (0.04)	1.2 (0.1)	1.3 (0.3)
38	1.5 (4.0)	2.2 (5.6)	2.6 (6.6)	2.9 (6.9)	0.6 (0.0)	0.9 (0.0)	1.1 (0.0)	1.1 (0.0)	0.6 (0.04)	0.9 (0.1)	1.2 (0.2)	1.3 (0.4)
28	0.8 (0.1)	1.2 (0.3)	2.1 (0.5)	2.7 (0.7)	0.7 (0.1)	1.0 (0.3)	1.2 (0.4)	1.4 (0.5)	0.6 (0.03)	0.9 (0.04)	1.1 (0.1)	1.3 (0.4)
∑Carcinogenic PAHs												
64	0.8 (0.2)	1.3 (0.6)	2.0 (1.1)	2.4 (1.3)	0.6 (0.01)	0.8 (0.2)	1.0 (0.2)	1.0 (0.3)	0.6 (0.0)	0.9 (0.0)	1.1 (0.0)	1.1 (0.0)
38	1.4 (3.5)	2.1 (5.5)	2.6 (6.5)	3.2 (6.7)	0.6 (0.0)	0.9 (0.0)	1.1 (0.0)	1.1 (0.0)	0.6 (0.1)	0.9 (0.1)	1.2 (0.3)	1.3 (0.4)
28	0.7 (0.1)	1.1 (0.2)	1.5 (0.5)	2.2 (0.5)	0.6 (0.1)	1.0 (0.3)	1.2 (0.4)	1.3 (0.4)	0.6 (0.04)	0.9 (0.1)	1.1 (0.1)	1.2 (0.1)
Fluoranthene												
64	3.1 (1.5)	8.0 (4.1)	11 (5.5)	13 (6.0)	1.0 (2.2)	1.4 (4.9)	1.9 (6.3)	2.4 (6.7)	0.7 (0.1)	1.0 (0.1)	1.4 (0.3)	1.7 (0.4)
38	1.4 (3.4)	2.2 (5.3)	2.7 (6.4)	2.9 (6.8)	0.6 (0.0)	0.9 (0.0)	1.1 (0.0)	1.1 (0.0)	0.6 (0.1)	1.0 (0.2)	1.2 (0.4)	1.3 (0.4)
28	0.8 (0.2)	1.5 (0.6)	2.7 (1.9)	3.3 (2.5)	0.7 (0.2)	1.0 (0.3)	1.3 (0.5)	1.4 (0.5)	0.6 (0.1)	1.0 (0.1)	1.2 (0.2)	1.3 (0.4)
Benzo(a)pyrene												
64	0.8 (0.1)	1.2 (0.3)	1.9 (0.4)	2.2 (0.4)	0.6 (0.0)	0.8 (0.2)	1.0 (0.2)	1.0 (0.3)	0.6 (0.0)	0.9 (0.0)	1.1 (0.0)	1.1 (0.0)
38	1.3 (3.4)	2.0 (5.3)	2.4 (6.5)	2.6 (6.9)	0.6 (0.0)	0.9 (0.0)	1.1(0.0)	1.1 (0.0)	0.6 (0.0)	0.9 (0.0)	1.1 (0.0)	1.1 (0.0)
28	0.7 (0.1)	1.0 (0.1)	1.3 (0.4)	1.4 (0.5)	0.6 (0.1)	1.0 (0.2)	1.2 (0.4)	1.3 (0.4)	0.6 (0.0)	0.9 (0.0)	1.1 (0.0)	1.1 (0.0)
	Asphalt Shingle (OKC)				**Metal (OKC)**				**Tar and Gravel (OKC)**			
	50%	**75%**	**90%**	**95%**	**50%**	**75%**	**90%**	**95%**	**50%**	**75%**	**90%**	**95%**
TSS	1.6 (1.7)	2.6 (2.7)	3.2 (3.6)	3.5 (4.1)	1.5 (2.8)	2.6 (5.1)	3.3 (7.0)	3.8 (7.4)	0.5 (1.0)	0.8 (1.5)	1.1 (1.8)	1.2 (1.9)
∑Commonly Detected PAHs	1.3 (1.0)	2.2 (2.2)	2.9 (3.3)	3.2 (4.0)	0.9 (1.1)	1.6 (2.5)	2.4 (3.6)	2.7 (4.3)	0.3 (0.3)	0.5 (0.5)	0.7 (0.6)	0.8 (0.6)
∑Carcinogenic PAHs	1.3 (2.2)	2.2 (2.2)	2.9 (3.2)	3.2 (4.1)	0.9 (1.0)	1.5 (2.4)	2.4 (3.5)	2.6 (3.8)	0.3 (0.3)	0.5 (0.5)	0.7 (0.6)	0.8 (0.6)
Fluoranthene	1.2 (0.9)	2.1 (2.0)	2.9 (3.2)	3.2 (3.7)	0.9 (1.0)	1.5 (2.7)	2.3 (3.8)	2.5 (4.1)	0.2 (0.4)	0.3 (0.6)	0.3 (0.8)	0.4 (0.9)
Benzo(a)pyrene	1.3 (1.0)	2.2 (2.2)	2.9 (3.1)	3.1 (3.6)	0.7 (0.3)	1.0 (0.4)	1.4 (0.7)	1.5 (0.8)	0.3 (0.3)	0.4 (0.6)	0.5 (0.7)	0.5 (0.8)

ΣCommonly Detected PAHs: fluoranthene, pyrene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, and ideno(1,2,3-cd)pyrene
ΣCarcinogenic PAHs: benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene

In the SIM samples, between 90 to 95% of PAHs were removed within the first 2 mm of runoff depth for the majority of the samples, as shown in Figures 3-14, 3-15, and 3-16, compared to approximately 75% of TSS (Figure 3-16). Figure 3-17 shows TSS and PAH percent mass removals for the OKC samples. In the OKC samples, all PAHs were removed within the first 0.78 mm of runoff from the tar and gravel roof, 90% of PAHs were removed within the first 2.4 mm of runoff from the metal roof, and 90% of PAHs were removed within the first 3.1 mm of runoff for the asphalt shingle roof.

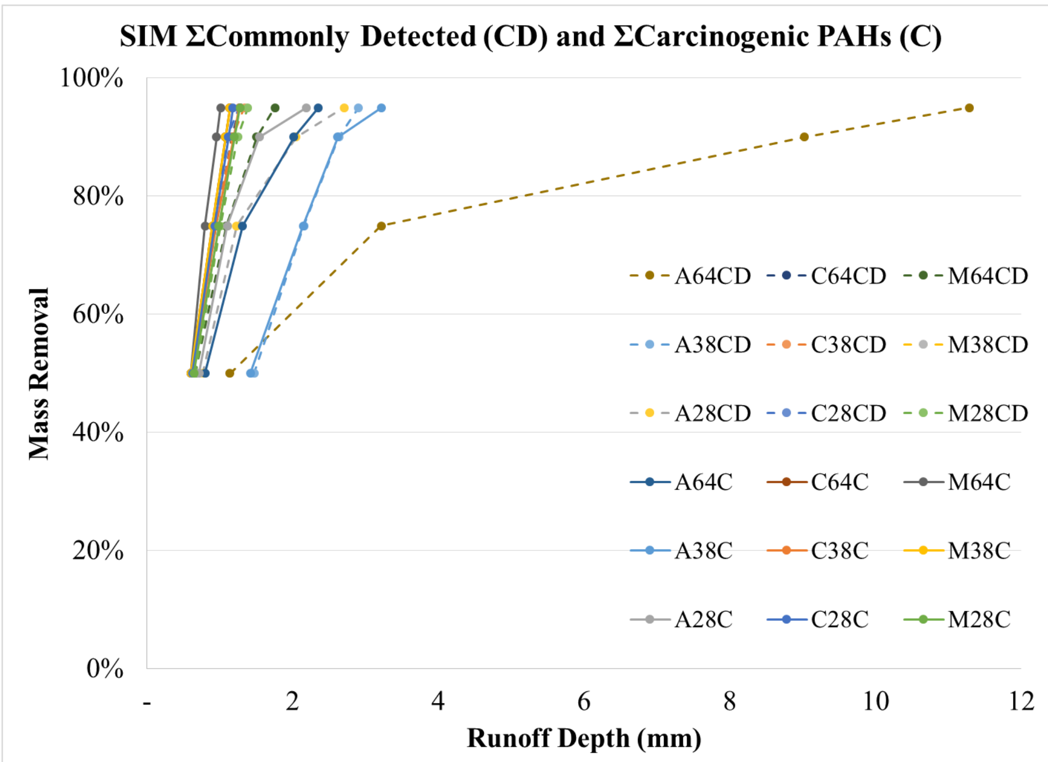

Figure 3-14. Percent mass removals of ΣCommonly Detected and ΣCarcinogenic PAHs versus runoff depth in the simulated rainfall event samples. The legend identifies the roof (A = asphalt shingle, C = clay tile, and M = metal), intensity (38 and 28 mm/hr), and PAH category (CD = ΣCommonly Detected PAHS and C = ΣCarcinogenic PAHs).

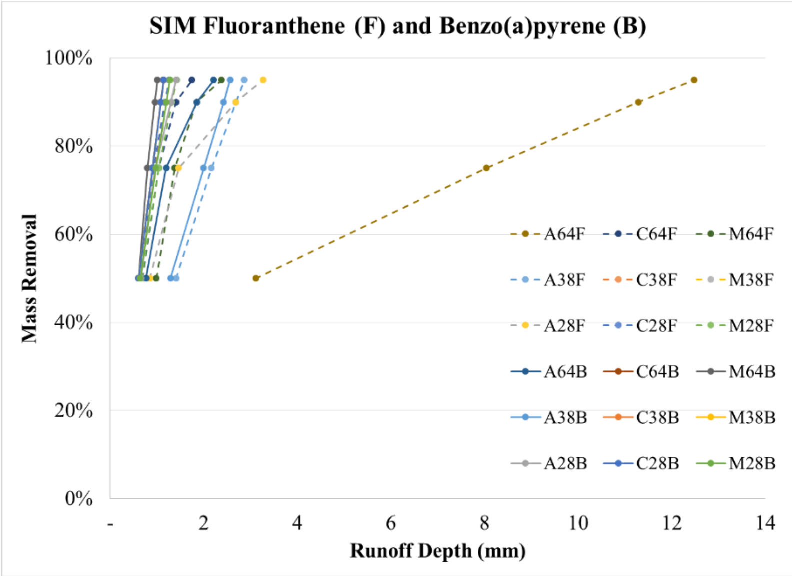

Figure 3-15. Percent mass removals of fluoranthene and benzo(a)pyrene versus runoff depth in the simulated rainfall event samples. The legend identifies the roof (A = asphalt shingle, C = clay tile, and M = metal), intensity (64, 38, and 28 mm/hr), and PAH category (F = fluoranthene and B = benzo(a)pyrene).

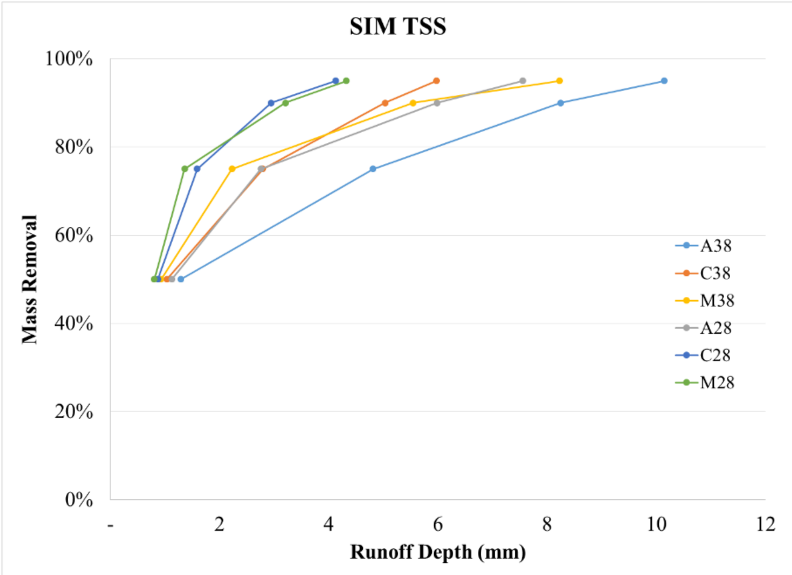

Figure 3-16. Percent mass removals of total suspended solids (TSS) versus runoff depth in the simulated rainfall event samples. The legend identifies the roof (A = asphalt shingle, C = clay tile, and M = metal), intensity (38 and 28 mm/hr)).

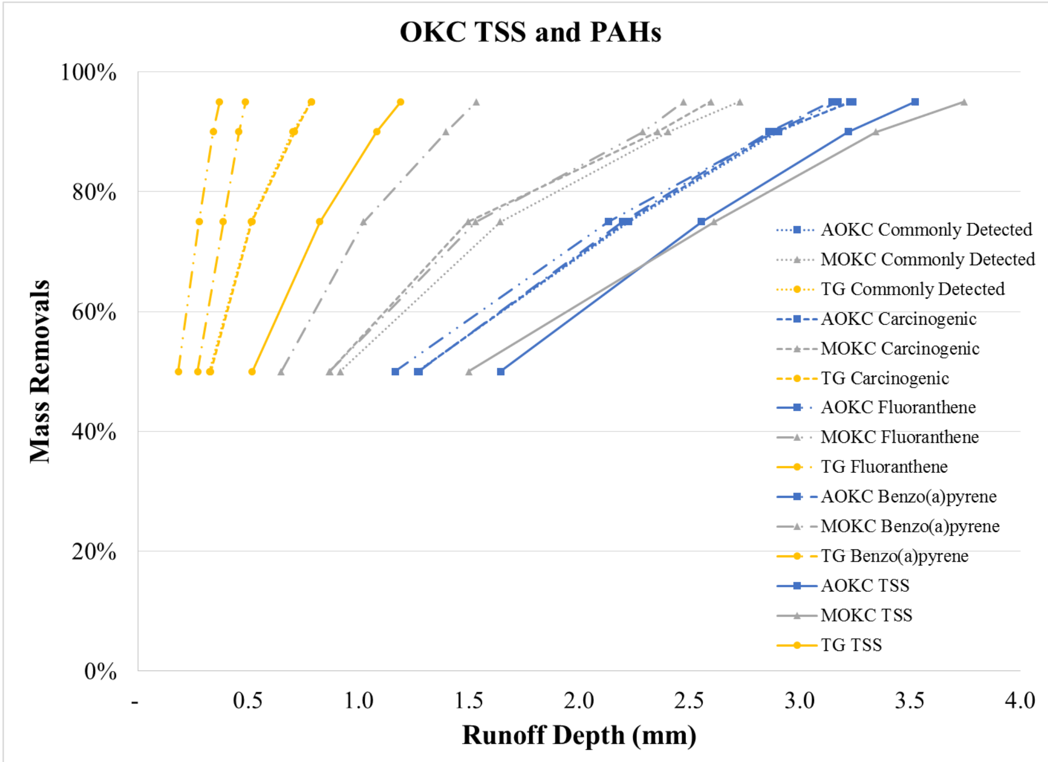

Figure 3-17. Percent mass removals of total suspended solids (TSS) and polycyclic aromatic hydrocarbons (PAHs) versus runoff depth in the OKC field samples. The legend identifies the roof (AOKC = asphalt shingle (blue), MOKC = metal (gray), and TG = tar and gravel (yellow), and pollutant category (ΣCommonly Detected PAHS, ΣCarcinogenic PAHs, fluoranthene, benzo(a)pyrene, and TSS).

TSS required higher runoff depths to reach the same percentage of removal as the PAHs. The asphalt shingle roof had the highest concentrations of PAHs, followed by the metal and then tar and gravel roof. The metal roof had the highest TSS concentrations, followed by the asphalt shingle and tar and gravel roofs. It was expected that the tar and gravel roof would have the highest concentrations of PAHs in its runoff. However, just the opposite occurred, which could be contributed to the roof's design. Flat gravel roofs have a higher initial abstraction as opposed to sloped roofs with a smoother surface area and can have typical depression and detention values between 2.5 and 7.5 mm (Farreny et al. 2011). The tar and gravel roof had poor catchment efficiencies compared to the asphalt shingle and metal roofs in OKC, as mentioned in Chapter 2. Farreny et al. (2011) also observed that flat, rough roofs can harvest up to 50% less than sloped, smooth roofs.

Ninety percent of fluoranthene and benzo(a)pyrene were observed to be diverted within the first 2.7 mm of runoff depth for all simulations on all roofs except the asphalt shingle roofs from the 64 mm/hr intensity. However, fluoranthene was observed to have a longer retention time in the roof runoff than benzo(a)pyrene, which could be due to the fact that fluoranthene has a higher solubility in water than benzo(a)pyrene. This observation agrees with research that has also suggested that lower molecular weight PAHs can be observed more frequently and at the highest concentrations in urban runoff (Rule et al. 2006).

Results on roof runoff quality from Chapter 2 showed EC, TSS, turbidity, and PAHs to be positively correlated to one another in the SIM and OKC samples ($\alpha = 0.05$). DiBlasi et al. (2008) also found a positive correlation to exist between PAHs and TSS in stormwater runoff. In this study, it was observed that the PAHs were removed at a faster rate than TSS (on a percent-mass basis). If the first flush diversion is based on removing the majority of TSS, then it is possible that the majority of PAHs will also be removed. Turbidity can serve as a surrogate for TSS, creating the potential for first-flush diverters to be designed to include sensors that measure the turbidity of the runoff. The diverters could be programmed to divert the runoff until a desired turbidity value is measured (Christensen et al. 2001, Jones et al. 2011, Miguntanna et al. 2010). However, difficulties were experienced in this study when attempting to continuously measure turbidity throughout a storm event. The turbidity sensors had interference in readings due to air bubbles in the runoff even though attempts were made to reduce bubbles forming when the runoff entered the downspout.

Results from this study showed that a larger first-flush diversion is required to remove the majority of PAHs observed in roof runoff than the 0.41 – 0.82 mm diversion recommended by the TWDB. Using a first flush of 0.82 mm would have only been adequate to remove 50% of the ΣCommonly Detected PAHs, ΣCarcinogenic PAHs, and benzo(a)pyrene observed in asphalt shingle, metal, and clay tile roof runoff; 50% of fluoranthene from metal and clay tile roof runoff; and 50% of TSS observed in metal roof runoff from the 28 mm/hr simulation. The metal roof in

OKC would have 50% of benzo(a)pyrene removed with a first flush of 0.82 mm. This first flush would also have removed at least 95% of PAHs and 75% of TSS in the tar and gravel roof runoff. However, the tar and gravel roof had a poor rainwater harvesting efficiency and results could have been skewed due to the high initial abstraction that occurred.

When comparing roofing materials from the SIM site, asphalt shingle roofs required the largest first flush diversion for TSS and PAHs. This makes sense as the asphalt shingle roofs were shown to be significantly different from the metal and clay tile roofs in regards to TSS and PAH concentrations while the metal and clay tile roofs were shown to not be significantly different from each other (Chapter 2).

From the OKC field samples, TSS concentrations in runoff from the asphalt shingle roof were shown to be significantly different from the metal and tar and gravel roofs while the metal and tar and gravel roofs were not significantly different from each other (Chapter 2). However, there were significant differences between all three OKC roofs in regards to ∑17PAHs, ∑Commonly Detected, fluoranthene, and benzo(a)pyrene PAH concentrations (Chapter II). The asphalt shingle roof was significantly different when comparing ∑Carcinogenic PAHs concentrations to the metal and tar and gravel roofs while the metal and tar and gravel roofs were not significantly different from each other.

Van Metre and Mahler (2003) observed no evidence that asphalt shingles were a source of PAHs in urban runoff, indicating that the PAHs observed in the roof runoff most likely originated from atmospheric deposition. The texture of roofing materials has an impact on retention, runoff behavior, and weathering processes (Göbel et al. 2007). The higher concentrations and longer retention times observed in the asphalt shingle compared to metal, clay tile, and the tar and gravel runoff can be attributed to the rougher surface texture of asphalt shingles.

3.4.2 First-Flush Recommendations Based on Percent Mass Removals

All of the diversions based on percent mass removals were compiled for each roof type from both the SIM and OKC studies. An upper-confidence limit (UCL) was constructed to determine the minimum diversion required for a specified percentage of samples to obtain a 50, 75, 90, and 95% mass removal of TSS and PAH contaminants. Following procedures outlined by Bender et al. (2011), these data were ranked from the smallest to largest diversion in order to obtain a distribution-free UCL for a desired percentile. Next, binomial probability was used to determine the UCL. The binomial probability density function, *B*, "calculates the probability that no more than *n* minus *u* values from a total of *n* observations exceed the (100*p*)th percentile of the sampled population, where *p* is the probability (p-value) of interest" (Bender et al. 2011),

$$B_{n,p}(u) = \binom{n}{u} p^u (1-p)^{n-u} \tag{3-7}$$

$$\binom{n}{u} = \frac{n!}{u!(n-u)!} \tag{3-8}$$

$$B(u-1, n, p) \geq 1 - \alpha \tag{3-9}$$

where *u* is the ranking of the smallest integer and α is the significance level. The measured value corresponding to *u* is the final first-flush diversion value recommended for the given roof type at the UCL based on a given percent mass removal.

When computing the UCL, an α = 0.1 and α = 0.2 were both used. These alpha levels indicate that there is a ten and 20% chance that a Type I error will occur. A Type I error would mean that the null hypothesis would be rejected when it is true. For example, by having an alpha of 0.2, the appropriate first-flush diversion has a 20% chance of being excluded from the UCL. As the end use of the harvested water from this research project is expected to consist of non-potable uses (i.e. watering lawns and irrigating gardens), these levels of risk were deemed acceptable.

Tables 3-3 and 3-4 provide summaries of the recommended first-flush diversions based on percent mass removals for TSS and PAHs for asphalt shingle, metal, clay tile, and tar and gravel roofs using an $\alpha = 0.1$ and $\alpha = 0.2$, respectively. All of the recommended first-flush diversions in Table 3-3 are based on a confidence that no more than ten percent of the diversions required to obtain a 50, 75, 90, and 95% percent mass removal exceed the recommendation listed in the Table 3-3. All of the recommended first-flush diversions in Table 3-4 are based on a confidence that no more than 20% of the diversions required to obtain a 50, 75, 90, and 95% percent mass removal exceed the recommendation listed in the Table 3-4.

Based on these first-flush diversion recommendations, it is apparent that asphalt shingle roofs require a much larger diversion than metal, clay tile, and even tar and gravel roofs. When observing the mass removal rates ($\alpha = 0.1$), the first-flush recommendation of 0.82 mm from the TWDB would only be enough to divert 50% of the PAHs from the clay tile roofs at an UCL of 85% (excluding benzo(a)pyrene, which had an UCL of 0%) and 50% of the commonly detected and carcinogenic PAHs from the tar and gravel roofs at an UCL of 57%. The tar and gravel roof has a 41 and 47% UCL that all of the fluoranthene and benzo(a)pyrene PAHs would be removed using the TWDB diversion recommendation.

When observing the mass removal rates ($\alpha = 0.2$), the first-flush recommendation of 0.82 mm from the TWDB would only be enough to divert 50% of benzo(a) pyrene from metal roofs (UCL 94%) and 50% of commonly detected and carcinogenic PAHs (UCL 90%) and 50% of benzo(a)pyrene (UCL 0.43%) and fluoranthene(UCL 90%) from clay tile roofs. The TWDB 0.82 diversion had greater success for the tar and gravel roof, removing up to 95% of PAHs fluoranthene (UCL 67%) and benzo(a)pyrene (UCL 74%) and 50% of the commonly detected and carcinogenic PAHs (UCL 83%). However, the tar and gravel roof had a very poor harvesting efficiency, which would make it undesirable for rainwater harvesting purposes. Diverting the first-flush based on mass removal rates of TSS requires a much larger diversion. However, PAHs were observed to generally require smaller diversions compared to TSS. Therefore, it is not necessary to divert the majority of TSS to divert the majority of the PAHs in the roof runoff.

Table 3-3. First-flush diversion recommendations (mm) for asphalt shingle, metal, clay tile, and tar and gravel roofs based on mass removals of total suspended solids (TSS) and polycyclic aromatic hydrocarbons (PAHs) ($\alpha = 0.1$).

Percent Mass Removals	Asphalt Shingle (n = 93)	Metal (n = 110)	Clay Tile (n = 72)	Tar & Gravel (n = 22)
TSS	87% Confidence	90% Confidence	72% Confidence	57% Confidence
50%	4.3	5.6	1.0	1.1
75%	7.5	9.7	4.8	1.6
90%	12.6	13.6	8.3	2.1
95%	15.4	16	10	2.4
Commonly Detected PAHs	93% Confidence	95% Confidence	85% Confidence	57% Confidence
50%	6.0	3.0	0.69	0.52
75%	82	5.4	1.0	0.89
90%	14	11	1.4	1.2
95%	17	12	2.0	1.3
Carcinogenic PAHs	93% Confidence	95% Confidence	85% Confidence	57% Confidence
50%	5.1	2.9	0.70	0.52
75%	7.6	4.8	1.0	0.88
90%	9.1	7.6	1.3	1.2
95%	12	8.7	1.3	1.3
Fluoranthene	93% Confidence	94% Confidence***	85% Confidence	41% Confidence*
50%	5.1	3.3	.81	0.20
75%	12	8.7	1.3	0.30
90%	17	11	1.9	0.36
95%	18	12	2.2	0.38
Benzo(a)pyrene	93% Confidence	95% Confidence	0% Confidence[a]	47% Confidence**
50%	4.0	1.0	0.60	0.42
75%	7.1	1.5	0.90	0.60
90%	9.0	2.2	1.1	0.72
95%	10	2.7	1.1	0.76

*n = 5; **n = 6; ***n = 27; [a]All samples had same diversions. Confidence limits vary between roof types due to differences in sample sizes.

Table 3-4. First-flush diversion recommendations (mm) for asphalt shingle, metal, clay tile, and tar and gravel roofs based on mass removals of total suspended solids (TSS) and polycyclic aromatic hydrocarbons (PAHs) ($\alpha = 0.2$).

Percent Mass Removals	Asphalt Shingle (n = 93)	Metal (n = 110)	Clay Tile (n = 72)	Tar & Gravel (n = 22)
TSS	92% Confidence	95% Confidence	93% Confidence	83% Confidence
50%	3.0	4.6	1.0	1.1
75%	7.3	6.6	4.8	1.6
90%	10	12	8.3	2.1
95%	12	13	10	2.4
Commonly Detected PAHs	90% Confidence	94% Confidence	90% Confidence	83% Confidence
50%	2.3	0.95	0.67	0.52
75%	6.1	2.4	1.0	0.89
90%	12	6.6	1.2	1.2
95%	15	8.8	1.9	1.3
Carcinogenic PAHs	90% Confidence	94% Confidence	90% Confidence	83% Confidence
50%	2.4	0.92	0.63	0.52
75%	5.9	1.5	0.95	0.88
90%	8.0	2.3	1.1	1.2
95%	8.7	2.7	1.2	1.3
Fluoranthene	90% Confidence	93% Confidence***	90% Confidence	67% Confidence*
50%	4.7	1.0	0.71	0.20
75%	12	1.6	1.1	0.30
90%	16	6.0	1.7	0.36
95%	18	6.3	2.0	0.38
Benzo(a)pyrene	90% Confidence	94% Confidence	0.43% Confidence[a]	74% Confidence**
50%	2.7	0.78	0.60	0.42
75%	5.6	1.4	0.90	0.60
90%	8.1	2.0	1.1	0.72
95%	8.7	2.2	1.1	0.76

*n = 5; **n = 6; ***n = 27; [a]All samples had same diversion. Confidence limits vary between roof types due to differences in sample sizes.

3.4.3 Polycyclic Aromatic Hydrocarbon Accumulation in Soils

Approximately 70% of the paired soil samples had higher PAH concentrations in the soils that were sampled from underneath a roof's downspout. The differences in these concentrations are likely due to PAHs that were atmospherically deposited onto the roof via dust and later washed away during a storm event. These results indicate that there is a potential for long-term accumulation of PAHs in soils that are watered with roof runoff that has no first-flush diversion. The presence of PAHs in soil samples taken away from a downspout show the ubiquitous nature of PAHs in the environment. It is noted that some of the "away" soils may not have been from the same time period as the "downspout" soils; some locations had recently been re-sodded prior to sample collections. Results of the soils analysis are given in Table 3-5, showing Σ17PAHs (>120 ng/g_{soil} reporting limit (RL)), ΣCommonly Detected PAHs (>25 ng/g_{soil} RL), ΣCarcinogenic PAHs (>23 ng/g_{soil} RL) fluoranthene (>5.0 ng/g_{soil} RL) and benzo(a)pyrene (> 3.3 ng/g_{soil} RL) concentrations. In the table, soil samples taken beneath the downspout are designated "DS" while soil samples taken away from the downspout are designated "AW". There was only one detection of TCEP in a DS sample (28.3 ng/g_{soil} at a 10 ng/g_{soil} RL) from the Public Information building and one detection of bifenthrin in a DS sample (76.7 ng/g_{soil} at a 3.33 ng/g_{soil} RL) from Residential House – STW in all of the 34 samples tested.

Table 3-6 lists risk-based screening levels of polycyclic aromatic hydrocarbons for residential soils and the frequency of both downspout and away soil samples exceeding the minimum risk-based screening levels. The screening levels are based on human-health risks and were calculated by the USEPA to determine whether or not levels of contamination measured at Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) hazardous waste sites warranted further investigation or site cleanup (USEPA 2013). The screening levels are not mandatory and are only meant to serve as a baseline for risk assessment.

Table 3-5. PAH concentrations (ng/g_{soil}) observed in soils. (DS: Downspout; AW: Away from Downspout)

Location	**Roof**	**Year Built**	**Σ17 PAHs**		**ΣCommonly Detected**		**ΣCarcinogenic**		**Fluoranthene**		**Benzo(a)pyrene**	
Home/Building - Location			DS	AW	DS	AW	DS	AW	DS	AW	DS	AW
Residential Home - OKC	Asphalt	1998	666	<120	510	50	354	44	117	<5.0	51	6.0
Jones Village - STW	Shingle	2000	3202	9917	2067	6616	1336	4541	590	1798	182	621
Allen Suites - STW		2001	<120	155	29	133	13	83	8.7	37	<3.3	12.7
Residential Barn - STW		2003	<120	<120	25	<25	<23	<23	10.3	<5.0	<3.3	<3.3
Residential House - STW		2004	742	<120	569	39	411	<23	116	14	60	3.3
BAE Lab – STW	Metal	1965	515	653	313	458	220	305	62	117	216	35
Physical Plant North - STW		1970	610	303	500	255	354	190	111	47	56	31
Career Tech - STW		1973	938	308	617	199	391	140	170	44	55	15
Fire Protection Safety Lab - STW		2003	4658	2751	3499	2057	2376	1393	792	485	357	216
Horticulture Pavilion - OKC		2004	3487	726	2597	544	1768	358	626	133	230	48
BAE Bioenergy Lab - STW		2008	276	<120	36	<25	<23	<23	17	<5.0	<3.3	<3.3
Thatcher - STW	Tar &	1925	25042	150	16170	35	13377	14	2966	16	2041	<3.3
Public Information – STW	Gravel	1930	831	725	565	556	347	370	161	141	52	58
Construction Technology Lab - STW		1968	1050	513	646	383	438	300	155	67	64	47
Human Services Education Center - OKC		1972	977	483	789	379	544	290	182	69	71	43
Physical Plant Administration - STW		1975	359	1213	254	955	183	595	56	264	29	73
Agriculture Resource Center - OKC		2008	651	179	511	152	386	118	94	24	54	16

Σ17 PAHs: naphthalene**,** 2-methyl naphthalene**,** acenaphthylene**,** acenaphthene**,** fluorene**,** phenanthrene**,** anthracene**,** fluoranthene**,** pyrene**,** benz(a)anthracene**,** chrysene**,** benzo(b)fluoranthene**,** benzo(k)fluoranthene**,** benzo(a)pyrene**,** ideno(1,2,3-cd)pyrene**,** dibenz(a,h)anthracene**,** and benzo(g,h,i)perylene
ΣCommonly Detected: fluoranthene, pyrene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, and ideno(1,2,3-cd)pyrene
ΣCarcinogenic: benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno(1,2,3-cd)pyrene, dibenz(a,h)anthracene

Table 3-6. Regional screening levels (SL) of polycyclic aromatic hydrocarbons for residential soils compared to the frequency of downspout (DS) and away (AW) soil samples having concentrations greater than the minimum SL listed (USEPA 2013a).

			Carcinogenic Target Risk = 1E-6				Noncancer Hazard Index = 1			
	Freq. DS Samples > Min. SL (%) (n=17)	Freq. AW Samples > Min. SL (%) (n=17)	Ingestion SL (mg/kg)	Dermal SL (mg/kg)	Inhalation SL (mg/kg)	Carcinogenic SL (mg/kg)	Ingestion SL (mg/kg)	Dermal SL (mg/kg)	Inhalation SL (mg/kg)	Noncarcinogenic SL (mg/kg)
Naphthalene	41	24			3.6E+00	3.6E+00	1.6E+03	4.3E+03	1.6E+02	1.4E+02
2-Methylnapthalene	24	6					3.1E+02	8.6E+02		2.3E+02
Acenaphthene	88	47					4.7E+03	1.3E+04		3.4E+03
Fluorene	53	12					3.1E+03	8.6E+03		2.3E+03
Anthracene	35	24					2.3E+04	6.4E+04		1.7E+04
Fluoranthene	100	82					3.1E+03	8.6E+03		2.3E+03
Pyrene	100	94					2.3E+03	6.4E+03		1.7E+03
Benz(a)anthracene	82	82	2.0E-01	5.3E-01	1.2E+04	1.5E-01				
Chrysene	100	88	2.0E+01	5.3E+01	1.2E+05	1.5E+01				
Benzo(b)fluoranthene	100	88	2.0E-01	5.3E-01	1.2E+04	1.5E-01				
Benzo(k)fluoranthene	88	76	2.0E+00	5.3E+00	1.2E+04	1.5E+00				
Benzo(a)pyrene	82	82	2.0E-02	5.3E-02	1.2E+03	1.5E-02				
Ideno(1,2,3-cd)pyrene	94	88	2.0E-01	5.3E-01	1.2E+04	1.5E-01				
Dibenz(a,h)anthracene	82	47	2.0E-02	5.3E-02	1.1E+03	1.5E-02				

PAH concentrations observed in the downspout soils were used to estimate the average annual PAH concentrations in the roof runoff from the buildings listed in Table 3-5. The transport properties of fluoranthene and benzo(a)pyrene are shown in Table 3-7, as well as the five other commonly detected PAHs observed from the water-based studies in order to provide a comparison between the PAH compounds. The minimum soil organic carbon/water partitioning coefficient (K_{OC}) and the minimum, median, and maximum degradation half -lives (λ) are provided in the table. The high K_{OC} values of the seven PAHs indicate their ability to sorb to the solid phase with little potential for advective or diffusional transport. The large computed *R* values (Equation 3-2) indicate little potential for the PAHs to move in the soil once they are applied. With no transport, PAHs can accumulate where they are applied and their concentration will only be reduced due to degradation or biological uptake.

Table 3-7. Transport properties of the commonly detected PAHs in the rooftop runoff study (Log K_{OC}: soil organic carbon/water partition coefficient; λ: degradation half-life; R: retardation) (NIOSH 2013, NCBI 2004).

Compound	Log K_{OC} Min	λ Min (days)	λ Max (days)	λ Median (days)	Minimum R
Fluoranthene	4.47	1100	2850	1975	1.48E+05
Pyrene	6.80	weeks	years	-	3.15E+07
Chrysene	4.49	77	387	232	1.55E+05
Benzo(b)fluoranthene	6.26	277	385	331	9.10E+06
Benzo(k)fluoranthene	5.19	65	1400	733	7.74E+05
Benzo(a)pyrene	2.97	229	309	269	4.65E+03
Ideno(1,2,3-cd)pyrene	6.88	139	730	435	3.79E+07

Assuming soil dry bulk density (ρ_b) = 1,500 kg/m^3, soil water content (θ) = 0.3, and soil organic content (f_{oc}) = 0.03.

The results for estimated fluoranthene and benzo(a)pyrene concentrations in each roof's runoff are shown in Table 3-8. The median half-life values for the two PAHs were used in the calculations. It was not feasible to show results based on the $\sum$17 PAHs due to wide range in half-life values between the 17 PAH compounds. Estimated fluoranthene concentrations in the roof runoff ranged between <1 – 18 ng/L while benzo(a)pyrene concentrations ranged between 1 – 90 ng/L. Benzo(a)pyrene's shorter half-life resulted in higher estimated runoff concentrations when compared to fluoranthene. Thatcher – STW had the highest observed PAH concentrations in its soils as well as in its estimated roof runoff concentrations. This can be attributed to the long potential accumulation time (87 years) observed at Thatcher – STW as well as the downspout's close proximity to a sidewalk. Stormwater runoff may have drained from the sidewalk to the soil at the downspout, further increasing the PAH load onto the soil. The estimated concentrations in the roof runoff were lower than concentrations observed in the water samples collected in the simulation and field studies. This is most likely due to dilution of the estimated concentration, as calculations were performed based on annual precipitation, and the uncertainty of the true half-lives of fluoranthene and benzo(a)pyrene in these specific soils.

Table 3-8. Estimations of fluoranthene and benzo(a)pyrene concentrations (ng/L) in roof runoff based on the concentrations (ng/g_{soil}) observed in soils sampled beneath downspouts.

Home/Building - Location	Roof	Year Built	Downspout Area (cm^2)	Estimated Accumulation Time in Soil at Time of Sampling (Years)	Fluoranthene [DS] ng/g_{soil}	Fluoranthene C_O ng/L	Benzo(a)pyrene [DS] ng/g_{soil}	Benzo(a)pyrene C_O ng/L
Residential Home - OKC	Asphalt	1998	38.7	14	117	3	51	8
Jones Village - STW	Shingle	2000	77.4	12	590	7	182	13
Allen Suites - STW		2001	77.4	11	8.7	<1	<3.3	-
Residential Barn - STW		2003	38.7	9	10.3	<1	<3.3	-
Residential House - STW		2004	38.7	8	116	4	60	9
BAE Lab – STW	Metal	1965	77.4	47	62	<1	216	13
Physical Plant North - STW		1970	77.4	42	111	<1	56	3
Career Tech - STW		1973	77.4	39	170	1	55	3
Fire Protection Safety Lab - STW		2003	77.4	9	792	9	357	21
Horticulture Pavilion - OKC		2004	103	8	626	6	230	11
BAE Bioenergy Lab - STW		2008	103	4	17	<1	<3.3	-
Thatcher - STW	Tar &	1925	155	87	2966	18	2041	90
Public Information – STW	Gravel	1930	103	82	161	1	52	4
Construction Technology Lab - STW		1968	155	44	155	<1	64	3
Human Services Education Center - OKC		1972	103	40	182	2	71	5
Physical Plant Administration - STW		1975	155	37	56	<1	29	1
Agriculture Resource Center - OKC		2008	103	4	94	2	54	4

[DS]: measured downspout concentration (ng/g_{soil}), C_O: estimated annual concentration in roof runoff (ng/l). Annual rainfall used for STW: 863.6 mm; annual rainfall used for OKC: 812.8 mm (Pettyjohn et al. 1983). Based on estimates that a single downspout serves approximately 1.2 m^2/cm^2 of downspout area. Runoff coefficients: asphalt shingles = 0.76 (based on OKC field study), metal = 0.92, tar and gravel = 0.62 (Farreny et al. 2011). Half-life of fluoranthene set at 1,975 days and benzo(a)pyrene at 269 days.

3.4.4 Continuous Conductivity Monitoring

EC is considered a leading parameter in assessing roof runoff quality (Farreny et al. 2011, Göbel et al. 2007). Continuous EC measurements were taken during storm events at OKC. These results provided a better understanding of EC concentrations throughout a storm event compared to the discrete sampling analysis of EC. OKC events did not have the same runoff volume per roof for each event and each roof did not have the same catchment area. Therefore, continuous EC measurements from OKC were normalized and plotted versus runoff depth for the asphalt shingle (Figure 3-18), metal (Figure 3-19), and tar and gravel roofs (Figure 3-20). The maximum EC concentrations, which also happened to be the initial concentrations, for each event are shown in Table 3-9.

Table 3-9. Maximum (initial) conductivity concentrations (µS/cm) from continuous measurements of roof runoff during storm events in OKC.

Date (2012)	Storm Event	Asphalt Shingle	Metal	Tar and Gravel
3 April	S1	-	71	-
11 April	S2	138	82	-
13 April	S3	133	-	45
19 April	S4	52	136	47
28 April	S5	-	135	96
11 May	S6	107	-	86
20 May	S7	-	143	162
29 May	S8	115	153	45
6 June	S9	133	121	493
15 June	S10	-	635	357
9 July	S11	752	766	751

Continuous EC measurements revealed an overall decreasing trend in concentrations throughout a storm event, indicating the presence of a first flush. The asphalt shingle EC was shown to decrease exponentially within the first 2 mm of runoff depth. The metal roof had a significant reduction in EC within the first 3 mm of runoff. Due to the flatness and poor catchment efficiency of the tar and gravel roof, the EC measurements in the runoff did not behave like the EC in the asphalt shingle and tar and gravel runoff. There was one event for the tar and gravel roof, S10, where the EC was shown to decrease significantly by the first 2 mm of runoff.

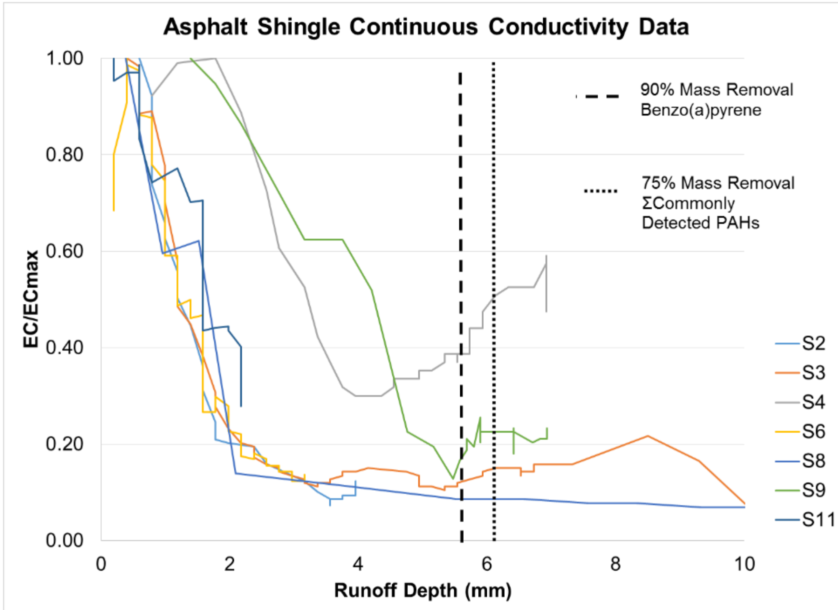

Figure 3-18. Normalized continuous conductivity measurements of the asphalt shingle roof runoff in OKC for each storm event (S) where field samples were collected. The runoff depths required for 90% mass removal of benzo(a)pyrene and 75% mass removal of the commonly detected PAHs (α = 0.2) observed in the study are also marked.

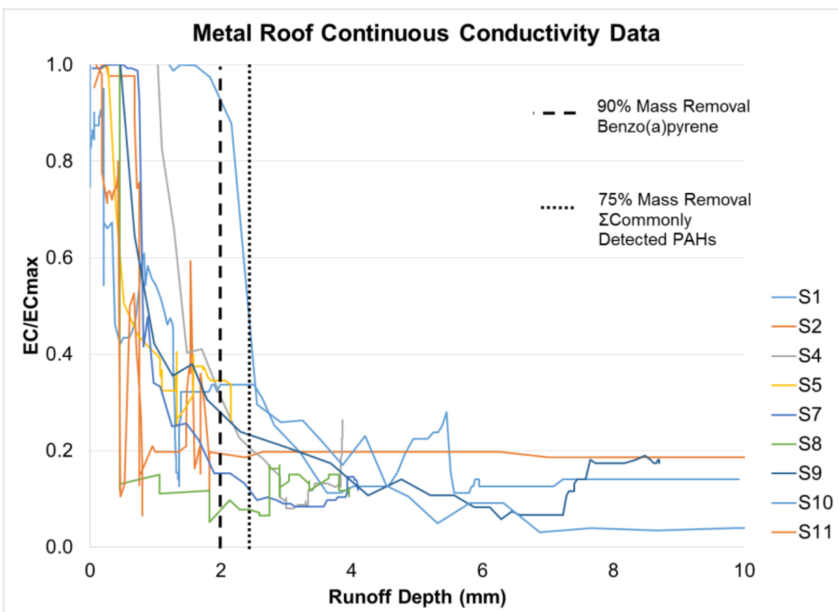

Figure 3-19. Normalized continuous conductivity measurements of metal roof runoff in OKC for each storm event (S) where field samples were collected. The runoff depths required for 90% mass removal of benzo(a)pyrene and 75% mass removal of the commonly detected PAHs (α = 0.2) observed in the study are also marked.

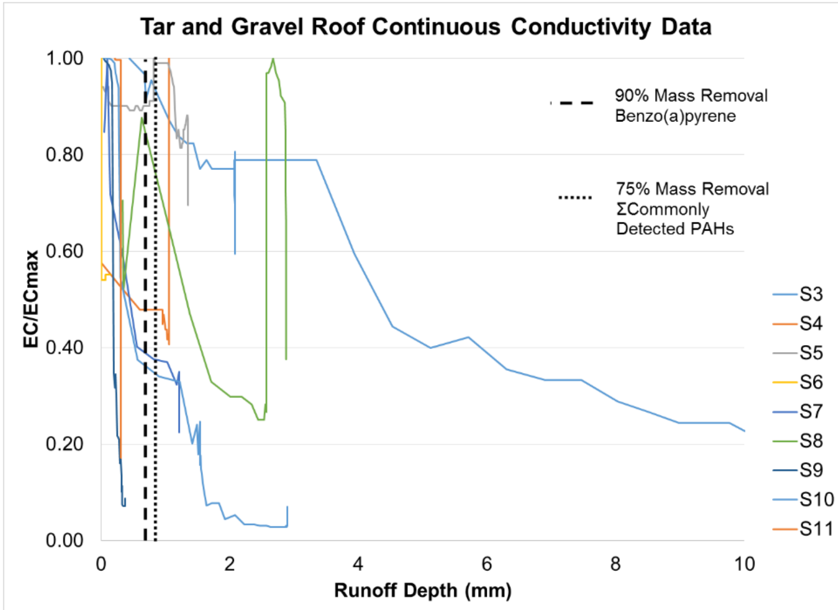

Figure 3-20. Normalized continuous conductivity measurements of the tar and gravel roof runoff in OKC for each storm event (S) where field samples were collected. The runoff depths required for 90% mass removal of benzo(a)pyrene and 75% mass removal of the commonly detected PAHs ($\alpha = 0.2$) observed in the study are also marked.

EC was shown to be positively correlated ($\alpha = 0.05$) to TSS, turbidity, and the presence of PAHs in roof runoff (Tables 2-24 to 2-30 for simulation samples and Tables 2-43 to 2-46 for OKC field samples). There is potential for designing automated first-flush diverters to divert runoff based on EC measurements that can, in turn, significantly divert contaminants like PAHs from storage tanks. Research and development on first-flush diverters equipped with automated control via sensors was also proposed by (Förster (1999)). Further research is needed in this area.

3.5 Summary and Conclusions

Fifty, 75, 90, and 95% mass removals of TSS and PAHs were calculated to determine a first-flush diversion for asphalt shingle, clay tile, metal, and flat gravel roofs. First-first diversions are recommended provided based on two separate confidence levels, $\alpha = 0.1$ and $\alpha = 0.2$, i.e. that no more than 10 or 20% of the diversions required to obtain a 50, 75, 90, and 95% percent mass removal exceed the listed recommendation diversion in Tables 3-3 and 3-4. The mass removals based on an $\alpha = 0.2$ require smaller diversions than those recommended based on an $\alpha = 0.1$. As the end use of the harvested water from this research project is expected to consist of non-potable uses (i.e. watering lawns and irrigating gardens), these levels of risk were deemed acceptable. Depending on the location of the RWH system, there may not be high levels of annual rainfall and diverting at an $\alpha = 0.1$ would waste more water than desired.

Asphalt shingle roofs required the largest diversions for PAHs, followed by metal, clay tile, then tar and gravel roofs. Asphalt shingles required a larger diversion to remove the first 50-75% of TSS, whereas metal roofs required larger diversions to remove 90-95% of TSS. When neglecting the tar and gravel roof due to its poor catchment efficiency, the clay tiles required the smallest diversions to remove the most TSS and PAHs. The 0.82 mm first-flush diversion recommended by the TWDB could, at best, remove up to 50% of PAHs for clay tile and metal roofs. Results from this study indicate a much higher diversion is needed in order to remove at least 50% of TSS or PAHs from asphalt shingle and metal roof runoff.

In order to remove 90% of TSS (confidence limit of 92%, $\alpha = 0.2$), 10, 12, and 8.2 mm would need to be diverted for asphalt shingle, metal, and clay tiled roofs, respectively. In order to remove ΣCommonly Detected PAHs with a confidence of at least 90% ($\alpha = 0.2$), a diversion of 12, 6.6, and 1.2 mm would be needed for asphalt shingle, metal, and clay tiled roofs, respectively. In order to remove 90% of ΣCarcinogenic PAHs with at least 90% confidence ($\alpha = 0.2$), a diversion of 8.0, 2.3, and 1.1 mm would be needed for asphalt shingle, metal, and clay tiled roofs, respectively.

Two separate first-flush effects were observed in the roof runoff between TSS and PAH concentrations, with the PAHs showing a faster rate of removal than TSS. Diverting the first-flush based on mass removal rates of TSS requires a much larger diversion than if one were to divert based on PAH removal. Therefore, when choosing a first-flush diversion, one may want to divert based on removing PAHs instead of TSS.

Continuous EC measurements from the OKC roofs revealed a strong first-flush occurrence for the asphalt shingle and metal roofs. The asphalt shingle runoff's EC was shown to decrease exponentially within the first 2 mm of runoff depth. Runoff from the metal roof had a significant reduction within the first 3 mm of runoff. Due to the flatness and poor catchment efficiency of the tar and gravel roof, the runoff did not exhibit a well-defined first flush; however, one event for the roof showed EC to decrease significantly by the first 2 mm of runoff. In order to harvest the most rainwater with the least amount of waste, there is potential to divert the first-flush based on EC measurements. Designing first-flush diverters with sensors detecting EC concentrations can automate the first-flush diversion process and make the diverters applicable to more than just one site-specific location.

While concentrations of PAHs in the roof runoff were observed to be three orders of magnitude below HBSLs (Chapter 2), a soil pilot-study showed that there is potential for long-term accumulation of PAHs in soils receiving roof runoff that has no first-flush diversion. Concentrations observed in the soils often exceeded minimum human-health risk-based screening levels for PAH concentrations in residential soils. Using harvested rainwater from rooftops to water lawns or irrigate gardens can potentially lead to long-term accumulation of PAHs in the soils. Therefore, it is recommended that an appropriate first-flush diversion be included in a rainwater harvesting collection system in order to reduce this potential of PAH accumulation. Further research is recommended on the effects PAH concentrations in soils can have on plants and vegetables, as one end use of harvested rainwater is irrigation for small gardens.

CHAPTER 4

OVERALL CONCLUSIONS

Rainwater harvesting (RWH) is a low impact development stormwater best management practice that involves the capture, diversion and storage of rainwater for later non-potable and potable use while also helping reduce stormwater runoff volume. Roof-based rainwater harvesting is implemented in both developed and developing countries. Rainwater harvesting can help alleviate demands on public water supply systems and promote better conservation practices in the public. While there are many benefits associated with utilizing rainwater harvesting practices, the water quality of the harvested rainwater is of great concern. One method recommended to improve the water quality of harvested rainwater is to divert the “first flush”, the portion of runoff where the majority of a rooftop’s dust and debris are believed to be washed away during the initial periods of a storm event. Research has shown varied recommendations in how much runoff should be diverted in the first flush in order to have satisfactory water quality in the RWH system. The overall goal of this research was to quantify first-flush diversion recommendations for roofs in Oklahoma based on roofing material and pollutants observed in the roof runoff.

The first objective of this research was to evaluate the water quality of roof runoff from different roofing materials based on irrigation water-quality guidelines for Oklahoma as well as based on concentrations of metals, total suspended solids (TSS), turbidity, polycyclic aromatic hydrocarbons (PAHs), phosphorus flame retardants (PFRs), and pyrethroid insecticides. This objective was addressed in Chapter 2. Runoff samples were collected from both constructed metal, asphalt shingle, and clay tile roofs during three simulated storm events in Stillwater, OK. Commercial metal and tar and gravel buildings, and one constructed asphalt shingle roof, were sampled during actual storm events in Oklahoma City. The runoff sampled from all roofs at both sites met “good” and “excellent” Oklahoma irrigation water-quality guidelines for conductivity (EC), sodium adsorption ratio (SAR), and boron. While present at trace levels (ng/L), concentrations never exceeded Health Based Screening Levels (HBSLs) for the PAH or pyrethroid insecticide compounds. There were no HBSL for the PFRs. Runoff from asphalt shingle roofs had the poorest water quality while clay tile roofs had the runoff with the best water quality. The tar and gravel roof from the study had a poor harvesting efficiency, which is believed to have affected the water quality results in the samples collected from the roof. Runoff from the metal roofs had the highest initial concentrations of PAHs in the simulation study; however, the PAHs were removed at a much faster rate from the metal roofs compared to the asphalt shingle roofs due to the roofs’ smoother surface catchment. Atmospheric deposition was observed to be the main contributor of pollutants in the roof runoff.

The second and third objectives of this research were to quantify a first-flush diversion based on mass removals of TSS and PAHs and to evaluate a first-flush occurrence in roof runoff based on continuous EC measurements throughout a storm event. All of the diversions based on percent mass removals were compiled for each roof type from both the SIM and OKC studies. An upper-confidence limit (UCL) was constructed using the binomial probability density function to determine the minimum diversion required for a specified percentage of samples to obtain a 50, 75, 90, and 95% mass removals of TSS and PAH contaminants. These objectives were addressed in Chapter 3. Two recommended first-flush diversion tables were created based on an $\alpha = 0.1$ (Table 3-3) and an $\alpha = 0.2$ (Table 3-4). These alpha levels indicated that there was a ten and 20% chance that a Type I error would occur. As the end use of the harvested rainwater was expected to consist of non-potable uses (i.e. watering lawns and irrigating gardens), these levels of risk were deemed acceptable.

Asphalt shingle roofs were observed to require the largest diversions for PAHs, followed by metal, clay tile, then tar and gravel roofs. Asphalt shingles required a larger diversion to remove the first 50-75% of TSS, whereas metal roofs required larger diversions to remove 90-95% of TSS. Two separate first-flush effects were observed in the roof runoff between TSS and PAH concentrations, with the PAHs showing a faster rate of removal than TSS. Diverting the first-flush based on mass removal rates of TSS requires a much larger diversion than if one were to divert based on PAH removal. When neglecting the tar and gravel roof due to its poor catchment efficiency, the clay tiles required the smallest diversions to remove the most TSS and PAHs. Results indicated that the "rule of thumb" diversion recommended by the Texas Water Development Board (TWDB) was no enough to divert the majority of the PAH and TSS pollutants observed in this study.

Continuous EC measurements from the OKC roofs revealed a strong first-flush occurrence for the asphalt shingle and metal roofs. Due to the flatness and poor catchment efficiency of tar and gravel roof, the runoff did not exhibit a well-defined first flush based on EC measurements. In order to harvest the most rainwater with the least amount of waste, there is potential to divert the first-flush based on EC measurements. Designing first-flush diverters with sensors detecting EC concentrations can automate the first-flush diversion process and make the diverters applicable to more than just one site-specific location.

Attempts were made to also take continuous turbidity measurements throughout a storm event. The turbidity readings were to serve as a surrogate for TSS measurements. However, the turbidity sensor had interferences with air bubbles and large particles in the downspout, even though attempts were made to reduce bubbles forming when the runoff entered the downspout. It is recommended that future work be done on improving a downspout's configuration to allow for accurate turbidity readings of roof runoff. If this research were to be repeated, it is advised that downspouts be further modified to reduce air bubbles in the downspouts from occurring and a screen placed at the inlet of the downspout to help reduce interference in the turbidity sensor. The setup should be experimented in the lab prior to installing in the field in order to ensure satisfactory results. As it is not practical to measure TSS in roof runoff in the field, installing a diverter with a turbidity sensor can serve as a surrogate for TSS measurements.

The final objective of this research was to perform a pilot-study to evaluate soils for potential long-term accumulation of PAHs when receiving roof runoff that did not contain a first-flush diversion. If PAHs were observed in higher concentrations in the soils beneath downspouts compared to soils that did not receive roof runoff, it would indicate a potential for PAH accumulation. Soils located directly underneath and away from roof downspouts were sampled and concentration differences between the paired samples were compared for the presence of PAH compounds. While concentrations of PAHs in the roof runoff were observed to be three orders of magnitude below HBSLs, the soil pilot-study showed that there is potential for long-term accumulation of PAHs in soils receiving roof runoff that has no first-flush diversion. Concentrations observed in the soils often exceeded minimum human-health risk-based screening levels proposed by the USEPA for PAH concentrations in residential soils. Using harvested rainwater from rooftops to water lawns or irrigate gardens can potentially lead to long-term accumulation of PAHs in the soils. Therefore, it is recommended that an appropriate first-flush diversion be included in a rainwater harvesting collection system in order to reduce this potential of PAH accumulation. Further research is recommended on the effects PAH concentrations in soils can have on plants and vegetables, as harvested rainwater may be used for irrigation.

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APPENDIX A

WATER QUALITY RESULTS FOR RAINFALL SIMULATION SAMPLES:

Simulation Intensity 64 mm/hr (August 2011)

Note: Amended Data (Background Concentrations in Simulation Water Removed from Sample Results for NO3N, SAR, B, Fe, Cu, Zn, and Mn); Zero (0) indicates <Detection Limit; Amended Data.

Sample ID	Orien-tation	pH	EC, µS/cm	NO3N, ppm	SAR	B, ppm	Fe, ppm	Cu, ppm	Zn, ppm	Mn, ppm
A1-1	NS	6.5802	179.8	2.175	0	0.1	0.15	0.16	0.13	0.11
A1-2	NS	6.797	52.4	0.175	0	0	0.02	0.02	0.02	0.01
A1-3	NS	6.9123	44.6	0.075	0	0	0.01	0.01	0.03	0
A1-4	NS	6.8927	40.5	0.075	0.025	0	0.01	0.01	0.02	0
A1-5	NS	6.749	39.1	0.075	0.025	0	0	0.01	0.01	0
A1-6	NS	6.9415	34.5	0	0.025	0	0	0.01	0.01	0
A2-1	NS	6.4875	184.5	2.275	0.025	0.1	0.11	0.16	0.09	0.09
A2-2	NS	6.8047	57.1	0.175	0	0	0.01	0.02	0.01	0
A2-3	NS	6.9991	43.6	0.075	0	0	0	0.01	0	0
A2-4	NS	6.9754	40.1	0.075	0	0	0	0.01	0	0
A2-5	NS	7.058	37.4	0.075	0	0	0	0.01	0	0
A2-6	NS	7.0248	34.2	0	0.025	0	0	0	0	0
A5-1	NS	6.4829	188.7	2.275	0.025	0.1	0.13	0.17	0.09	0.09
A5-2	NS	6.7923	69.7	0.175	0.225	0	0.01	0.02	0.02	0
A5-3	NS	6.8758	52.4	0.075	0.125	0	0.01	0.01	0.01	0
A5-4	NS	6.8064	40.1	0.075	0.025	0	0	0.01	0	0
A5-5	NS	6.8486	38.2	0	0.025	0	0	0.01	0	0
A5-6	NS	6.9976	35.6	0	0.025	0	0	0	0	0
C1-1	NS	6.9219	89.1	1.775	0	0	0.02	0.01	0.03	0
C1-2	NS	6.8525	39.2	0.075	0	0	0.01	0	0.01	0
C1-3	NS	6.9548	35.1	0.075	0.025	0	0.01	0.01	0	0
C1-4	NS	6.9927	34.2	0.075	0.025	0	0	0	0	0
C1-5	NS	7.0626	33.6	0.075	0.025	0	0	0	0	0
C1-6	NS	7.0807	33.8	0	0.025	0	0	0	0	0
C2-1	NS	7.1101	93.9	1.875	0	0	0.01	0	0.01	0
C2-2	NS	7.1281	41.8	0.275	0.025	0	0	0	0.01	0
C2-3	NS	7.2724	35.9	0.075	0.025	0	0	0	0	0
C2-4	NS	7.2432	36.6	0.075	0.025	0	0	0	0	0
C2-5	NS	7.2668	34.6	0.075	0.025	0	0	0	0	0
C2-6	NS	7.2825	34.4	0	0.025	0	0	0.01	0	0
C5-1	NS	7.0239	94.2	1.875	0	0	0.01	0	0.01	0
C5-2	NS	7.0634	38.5	0.075	0.025	0	0	0	0	0
C5-3	NS	7.1784	35.4	0	0.025	0	0	0	0	0
C5-4	NS	6.9314	35.9	0.075	0.025	0	0	0.01	0	0

Sample ID	Orien-tation	pH	EC, µS/cm	NO3N, ppm	SAR	B, ppm	Fe, ppm	Cu, ppm	Zn, ppm	Mn, ppm
C5-5	NS	7.0047	34.9	0.075	0.025	0	0	0	0	0
C5-6	NS	6.9885	34.8	0	0.025	0	0	0	0	0
M1-1	NS	7.0182	106.2	1.675	0	0	0.01	0.01	0.07	0
M1-2	NS	7.025	41.6	0.075	0.025	0	0	0	0.01	0
M1-3	NS	7.0144	35.9	0.075	0.025	0	0	0.01	0	0
M1-4	NS	6.9658	35.4	0	0.025	0	0	0	0.01	0
M1-5	NS	7.0425	34.2	0.075	0.025	0	0	0	0	0
M1-6	NS	7.1151	34.4	0	0.025	0	0	0	0.01	0
M2-1	NS	6.9256	94.2	1.675	0	0	0.02	0	0.1	0
M2-2	NS	7.0338	40.6	0.075	0	0	0	0	0.01	0
M2-3	NS	7.0369	36.5	0.075	0.025	0	0	0	0.01	0
M2-4	NS	7.0122	34.5	0	0.025	0	0	0	0	0
M2-5	NS	7.0313	34.5	0.075	0.025	0	0	0	0.01	0
M2-6	NS	7.1145	33.7	0	0.025	0	0	0	0	0
M5-1	NS	6.9838	101.7	1.575	0	0	0.01	0	0.07	0
M5-2	NS	7.0972	40.1	0.075	0	0	0	0	0.01	0
M5-3	NS	7.05	35.6	0	0.025	0	0	0	0	0
M5-4	NS	7.0944	35.1	0	0.025	0	0	0	0	0
M5-5	NS	7.0936	35.2	0.075	0.025	0	0	0	0	0
M5-6	NS	7.1197	34.6	0	0.025	0	0	0	0	0
A3-1	EW	6.5819	195.6	2.375	0	0.2	0.14	0.18	0.09	0.13
A3-2	EW	6.9225	54.4	0.175	0	0	0.01	0.01	0.01	0
A3-3	EW	6.9768	44.6	0.075	0	0	0	0.01	0	0
A3-4	EW	6.983	41.3	0	0	0	0	0	0	0
A3-5	EW	6.9669	39.9	0.075	0	0	0	0	0	0
A3-6	EW	6.9602	37.5	0	0	0	0	0	0	0
A4-1	EW	6.4765	194	1.975	0.025	0.1	0.14	0.18	0.14	0.13
A4-2	EW	6.783	56.3	0.175	0	0	0.01	0.01	0.01	0
A4-3	EW	6.8482	49.9	0.075	0.025	0	0	0.01	0.01	0
A4-4	EW	6.8761	43.5	0.075	0	0	0	0.01	0.01	0
A4-5	EW	6.9251	40.2	0.075	0	0	0	0	0.01	0
A4-6	EW	6.8968	36.8	0	0.025	0	0	0	0	0
A6-1	EW	6.5033	206	2.175	0.025	0.2	0.13	0.17	0.09	0.13
A6-2	EW	6.8729	57.5	0.075	0	0	0.01	0.02	0.01	0
A6-3	EW	7.0822	46.3	0.075	0	0	0	0.01	0	0
A6-4	EW	7.0182	44	0.075	0	0	0	0.01	0	0
A6-5	EW	7.0125	41.2	0.075	0	0	0	0.01	0	0
A6-6	EW	6.8447	38.1	0	0.025	0	0	0	0	0
C3-1	EW	7.1316	92.3	2.075	0	0	0.01	0	0	0
C3-2	EW	7.0294	45.1	0.175	0	0	0	0	0	0

Sample ID	Orien-tation	pH	EC, µS/cm	NO3N, ppm	SAR	B, ppm	Fe, ppm	Cu, ppm	Zn, ppm	Mn, ppm
C3-3	EW	6.9954	40.4	0.075	0.025	0	0	0	0	0
C3-4	EW	7.0491	37.9	0.075	0.025	0	0	0	0	0
C3-5	EW	7.0416	38.3	0.075	0.025	0	0	0	0	0
C3-6	EW	7.1116	37.4	0.075	0.025	0	0	0	0	0
C4-1	EW	6.888	110.2	1.775	0	0	0.02	0.01	0.02	0
C4-2	EW	6.9359	40.5	0.175	0	0	0	0	0	0
C4-3	EW	7.0301	37.7	0.175	0.025	0	0	0	0	0
C4-4	EW	7.0436	36.4	0.075	0.025	0	0	0	0	0
C4-5	EW	7.0447	36.1	0.075	0.025	0	0	0	0	0
C4-6	EW	7.0601	35.6	0	0.025	0	0	0	0	0
C6-1	EW	7.2	102.6	2.075	0	0	0.02	0	0	0
C6-2	EW	7.3025	43.9	0.175	0	0	0	0	0	0
C6-3	EW	7.2591	39.9	0.075	0	0	0	0	0	0
C6-4	EW	7.3185	39.8	0.075	0	0	0	0	0	0
C6-5	EW	7.3066	38.3	0.075	0	0	0	0	0	0
C6-6	EW	7.2667	37.6	0.075	0.025	0	0	0	0	0
M3-1	EW	7.2184	102.9	1.875	0	0	0.03	0	0.04	0
M3-2	EW	7.1633	44.2	0.075	0	0	0	0	0.01	0
M3-3	EW	7.0538	38.2	0.075	0.025	0	0	0	0.01	0
M3-4	EW	7.0464	36.4	0	0.025	0	0	0	0	0
M3-5	EW	7.0816	36.1	0	0.025	0	0	0	0.01	0
M3-6	EW	7.0793	35.3	0	0.025	0	0	0	0	0
M4-1	EW	7.1081	98.3	1.675	0	0	0.01	0	0.07	0
M4-2	EW	7.1476	39	0	0	0	0	0	0	0
M4-3	EW	7.0651	36.1	0	0.025	0	0	0	0	0
M4-4	EW	7.0815	35.3	0	0.025	0	0	0	0	0
M4-5	EW	7.0921	35.4	0	0.025	0	0	0	0	0
M4-6	EW	7.359	34.7	0	0.025	0	0	0	0	0
M6-1	EW	7.1547	110.1	2.075	0	0	0.01	0	0.07	0
M6-2	EW	7.3532	44.2	0.075	0	0	0	0	0.01	0
M6-3	EW	7.284	38.3	0.075	0.025	0	0	0	0.01	0
M6-4	EW	7.3316	37.5	0.075	0.025	0	0	0	0.01	0
M6-5	EW	7.3202	36.5	0	0.025	0	0	0	0	0
M6-6	EW	7.3499	35.1	0	0.025	0	0	0	0	0

Simulation Intensity 38 mm/hr (November 2011)

Note: Amended Data (Background Concentrations in Simulation Water Removed from Sample Results for NO3N, SAR, B, Fe, Cu, Zn, and Mn); Zero (0) indicates <Detection Limit; Amended Data.

Sample ID	Orien-tation	pH	EC, µS/cm	NO3N, ppm	SAR	B, ppm	Fe, ppm	Cu, ppm	Zn, ppm	Mn, ppm
M2-1	NS	7.2871	43.3	0.3	0	0	0.005	0.01	0.03	0
M2-2	NS	7.1403	26.1	0	0	0	0	0	0.01	0
M2-3	NS	7.0496	23.9	0	0	0	0	0	0.01	0
M2-4	NS	7.0149	23.1	0	0	0	0	0	0.01	0
M2-5	NS	7.0364	22.1	0	0	0	0	0	0	0
M2-6	NS	7.0348	22.6	0	0.1	0	0	0	0	0
C2-1	NS	7.5255	65.7	0.7	0	0	0.005	0	0	0
C2-2	NS	7.1687	35	0.1	0	0	0	0	0	0
C2-3	NS	7.1262	28.7	0	0	0	0	0	0	0
C2-4	NS	7.1103	26.8	0	0	0	0	0	0	0
C2-5	NS	7.0736	28.5	0.1	0	0	0	0	0	0
C2-6	NS	7.1021	26.3	0	0	0	0	0	0	0
A2-1	NS	7.2918	64.7	0.6	0	0	0.015	0.03	0	0.01
A2-2	NS	7.1274	32.8	0.1	0	0	0	0.01	0	0
A2-3	NS	7.0991	28.4	0	0	0	0	0	0	0
A2-4	NS	7.0937	26.3	0	0	0	0	0	0	0
A2-5	NS	7.098	25.8	0	0	0	0	0	0	0
A2-6	NS	7.0812	25.4	0	0	0	0	0	0	0
M1-1	NS	7.3888	41.8	0.3	0	0	0.025	0	0.02	0
M1-2	NS	7.3171	25.5	0	0	0	0	0	0.01	0
M1-3	NS	7.116	24.4	0	0	0	0	0	0.01	0
M1-4	NS	7.1382	23.4	0	0	0	0	0	0	0
M1-5	NS	7.0776	22.4	0	0	0	0	0	0	0
M1-6	NS	7.1075	22.3	0	0.1	0	0	0	0	0
C1-1	NS	7.6333	53.4	0.6	0	0	0	0	0	0
C1-2	NS	7.1936	28.6	0	0	0	0	0.01	0	0
C1-3	NS	7.1156	25.4	0	0	0	0	0	0	0
C1-4	NS	7.1129	24.7	0	0	0	0	0	0	0
C1-5	NS	7.0946	23.9	0	0	0	0	0	0	0
C1-6	NS	7.12	24.7	0	0.1	0	0	0	0	0
A1-1	NS	7.2909	66.5	0.6	0	0	0	0.03	0	0.01
A1-2	NS	7.2479	31.5	0	0	0	0	0.01	0	0
A1-3	NS	7.1773	27.3	0	0	0	0	0	0	0
A1-4	NS	7.1376	25.8	0	0	0	0	0	0	0
A1-5	NS	7.1529	25.3	0	0	0	0	0	0	0

Sample ID	Orien-tation	pH	EC, µS/cm	NO3N, ppm	SAR	B, ppm	Fe, ppm	Cu, ppm	Zn, ppm	Mn, ppm
A1-6	NS	7.1484	24.8	0	0	0	0	0	0	0
M5-1	NS	7.6666	40.2	0.2	0	0	0.005	0	0	0.01
M5-2	NS	7.2461	26.1	0	0	0	0	0	0.01	0
M5-3	NS	7.1255	25.3	0	0	0	0	0	0.01	0
M5-4	NS	6.9906	23.8	0	0	0	0	0	0.01	0
M5-5	NS	7.0097	23.4	0	0	0	0	0	0.01	0
M5-6	NS	7.0798	23.8	0	0	0	0	0	0	0
C5-1	NS	7.215	62.4	0.7	0	0	0.045	0	0	0
C5-2	NS	6.9571	33.9	0.1	0	0	0	0	0	0
C5-3	NS	6.9791	30.7	0.1	0	0	0	0	0	0
C5-4	NS	7.019	27	0	0	0	0	0	0	0
C5-5	NS	7.0606	26.8	0	0	0	0	0	0	0
C5-6	NS	7.1003	25.2	0	0	0	0	0	0	0
A5-1	NS	7.0961	63.3	0.5	0	0	0.035	0.02	0	0.01
A5-2	NS	6.9826	33.3	0	0	0	0	0.01	0	0
A5-3	NS	7.0277	28.1	0	0	0	0	0	0	0
A5-4	NS	6.9453	26.4	0	0	0	0	0	0	0
A5-5	NS	6.8995	26.4	0	0	0	0	0	0	0
A5-6	NS	7.0947	25	0	0	0	0	0	0	0
M3-1	EW	7.4981	51	0.2	0	0	0	0	0	0
M3-2	EW	7.2393	27.3	0.1	0	0	0	0	0	0
M3-3	EW	7.0996	23.3	0	0	0	0	0	0	0
M3-4	EW	7.0694	22.4	0	0	0	0	0	0	0
M3-5	EW	7.0592	21.9	0	0	0	0	0	0	0
M3-6	EW	7.0341	21	0	0	0	0	0	0	0
C3-1	EW	7.3198	62.1	0.4	0	0	0	0	0	0
C3-2	EW	7.1468	31.5	0.1	0	0	0	0	0	0
C3-3	EW	7.0866	26.1	0.1	0	0	0	0	0	0
C3-4	EW	7.021	23.9	0.1	0	0	0	0	0	0
C3-5	EW	7.0258	23.2	0.1	0	0	0	0	0	0
C3-6	EW	6.9585	22.3	0.1	0	0	0	0	0	0
A3-1	EW	7.0185	65.4	0.4	0	0	0	0.02	0	0
A3-2	EW	7.0927	29.7	0.1	0	0	0	0	0	0
A3-3	EW	7.0888	26.2	0.1	0	0	0	0	0	0
A3-4	EW	7.0966	24.9	0	0	0	0	0	0	0
A3-5	EW	7.0765	24.3	0	0	0	0	0	0	0
A3-6	EW	7.0595	23.6	0	0	0	0	0	0	0
M4-1	EW	7.756	47.9	0.2	0	0	0	0	0	0
M4-2	EW	7.3945	27.9	0.1	0	0	0	0	0	0
M4-3	EW	7.2316	24.3	0	0	0	0	0	0	0

Sample ID	Orien-tation	pH	EC, µS/cm	NO3N, ppm	SAR	B, ppm	Fe, ppm	Cu, ppm	Zn, ppm	Mn, ppm
M4-4	EW	7.1982	23	0	0	0	0	0	0	0
M4-5	EW	7.2008	23	0	0	0	0	0	0	0
M4-6	EW	7.0509	22.9	0.1	0	0	0	0	0	0
C4-1	EW	7.3209	55.3	0.3	0	0	0	0	0	0
C4-2	EW	7.1906	29.2	0.1	0	0	0	0	0	0
C4-3	EW	7.1126	24.3	0.1	0	0	0	0	0	0
C4-4	EW	7.1041	23.4	0.1	0	0	0	0	0	0
C4-5	EW	7.0529	23.1	0.1	0	0	0	0	0	0
C4-6	EW	7.0416	22.1	0.1	0	0	0	0	0	0
A4-1	EW	7.0245	27.2	0	0	0	0	0	0	0
A4-2	EW	6.9249	35.4	0.1	0	0	0	0	0	0
A4-3	EW	6.9658	29.9	0.1	0	0	0	0	0	0
A4-4	EW	6.8958	77.7	0.5	0	0	0	0.04	0	0
A4-5	EW	7.0249	26.9	0	0	0	0	0	0	0
A4-6	EW	6.2435	26	0	0	0	0	0	0	0
M6-1	EW	7.1997	50.8	0.2	0	0	0.005	0	0.03	0
M6-2	EW	7.1259	29.7	0.1	0	0	0	0	0.02	0
M6-3	EW	7.0793	21.1	0	0	0	0	0	0.01	0
M6-4	EW	6.9893	24.2	0	0	0	0	0	0.01	0
M6-5	EW	6.9932	23.8	0	0	0	0	0	0.01	0
M6-6	EW	6.9875	23.1	0.1	0	0	0	0	0	0
C6-1	EW	7.3204	57.4	0.3	0	0	0	0	0	0
C6-2	EW	7.1613	31.2	0.1	0	0	0	0	0	0
C6-3	EW	7.1021	26	0.1	0	0	0	0	0	0
C6-4	EW	7.0559	24.5	0.1	0	0	0	0	0	0
C6-5	EW	7.0538	23.7	0.1	0	0	0	0	0	0
C6-6	EW	7.0038	22.9	0	0	0	0	0	0	0
A6-1	EW	6.9679	74.5	0.5	0	0	0	0.02	0	0
A6-2	EW	7.0495	32.1	0.1	0	0	0	0.01	0	0
A6-3	EW	7.0215	27.6	0.1	0	0	0	0	0	0
A6-4	EW	7.0633	26.6	0	0	0	0	0	0	0
A6-5	EW	7.0175	25.3	0	0	0	0	0	0	0
A6-6	EW	7.0185	24.8	0.1	0	0	0	0	0	0

Simulation Intensity 28 mm/hr (February 2012)

Note: Amended Data (Background Concentrations in Simulation Water Removed from Sample Results for NO3N, SAR, B, Fe, Cu, Zn, and Mn); Zero (0) indicates <Detection Limit; Amended Data.

Sample ID	Orien-tation	pH	EC, µS/cm	NO3N, ppm	SAR	B, ppm	Fe, ppm	Cu, ppm	Zn, ppm	Mn, ppm
M2-1	NS	7.1415	21	0	0	0	0	0	0.00425	0
M2-2	NS	6.8647	12.6	0	0	0	0	0	0	0
M2-3	NS	6.7126	10.58	0	0	0	0	0	0	0
M2-4	NS	6.6016	9.5	0	0	0	0	0	0	0
M2-5	NS	6.5593	9.19	0	0	0	0	0	0	0
M2-6	NS	6.5083	8.96	0	0	0	0	0	0	0
C2-1	NS	7.263	32.3	0.3	0	0	0.0025	0	0	0
C2-2	NS	6.9621	16.69	0	0	0	0	0	0	0
C2-3	NS	6.7256	12.1	0	0	0	0	0	0	0
C2-4	NS	6.5464	10.44	0	0	0	0	0	0	0
C2-5	NS	6.5313	9.89	0	0	0	0	0	0	0
C2-6	NS	6.4247	9.04	0	0	0	0	0	0	0
A2-1	NS	6.9995	56.2	0.6	0	0	0	0.025	0	0
A2-2	NS	6.8514	17.27	0	0	0	0	0	0	0
A2-3	NS	6.7485	14.41	0.1	0	0	0	0	0	0
A2-4	NS	6.7707	12.92	0	0	0	0	0	0	0
A2-5	NS	6.7284	12.5	0	0	0	0	0	0	0
A2-6	NS	6.6804	11.4	0	0	0	0	0	0	0
M1-1	NS	7.45	21.4	0	0	0	0	0	0	0
M1-2	NS	7.0621	13.03	0	0	0	0	0	0	0
M1-3	NS	6.7165	10.12	0	0	0	0	0	0	0
M1-4	NS	6.6203	9.04	0	0	0	0	0	0	0
M1-5	NS	6.5445	8.46	0	0	0	0	0	0	0
M1-6	NS	6.4383	8.12	0	0	0	0	0	0	0
C1-1	NS	7.4675	26.1	0.2	0	0	0	0	0	0
C1-2	NS	6.9466	13.04	0	0	0	0	0	0	0
C1-3	NS	6.6964	10.53	0	0	0	0	0	0	0
C1-4	NS	6.5892	9.52	0	0	0	0	0	0	0
C1-5	NS	6.5445	9.16	0	0	0	0	0	0	0
C1-6	NS	6.4265	8.08	0	0	0	0	0	0	0
A1-1	NS	6.9781	57.9	0.6	0	0	0	0.031	0	0
A1-2	NS	6.9121	18.03	0	0	0	0	0	0	0
A1-3	NS	6.8399	14.43	0	0	0	0	0	0	0
A1-4	NS	6.8333	13.61	0	0	0	0	0	0	0
A1-5	NS	6.785	12.12	0	0	0	0	0	0	0

Sample ID	Orien-tation	pH	EC, µS/cm	NO3N, ppm	SAR	B, ppm	Fe, ppm	Cu, ppm	Zn, ppm	Mn, ppm
A1-6	NS	6.677	11.62	0	0	0	0	0	0	0
M5-1	NS	8.195	25.2	0	0	0	0	0	0	0
M5-2	NS	7.0561	13.49	0	0	0	0	0	0	0
M5-3	NS	6.6842	9.65	0	0	0	0	0	0	0
M5-4	NS	6.5076	8.53	0	0	0	0	0	0	0
M5-5	NS	6.4282	8.17	0	0	0	0	0	0	0
M5-6	NS	6.3833	8.05	0	0	0	0	0	0	0
C5-1	NS	7.3253	29.1	0.2	0	0	0	0	0	0
C5-2	NS	6.9003	13.01	0	0	0	0	0	0	0
C5-3	NS	6.6063	10.42	0	0	0	0	0	0	0
C5-4	NS	6.4443	9.55	0	0	0	0	0	0	0
C5-5	NS	6.4343	9.06	0	0	0	0	0	0	0
C5-6	NS	6.2417	8.89	0	0	0	0	0	0	0
A5-1	NS	6.906	60.1	0.6	0	0	0	0.034	0	0
A5-2	NS	6.8975	18.47	0	0	0	0	0	0	0
A5-3	NS	6.768	14.64	0	0	0	0	0	0	0
A5-4	NS	6.7312	13.42	0	0	0	0	0	0	0
A5-5	NS	6.7623	12.41	0	0	0	0	0	0	0
A5-6	NS	6.6764	12.19	0	0	0	0	0	0	0
M3-1	EW	7.218	21.8	0.1	0	0	0	0	0.00625	0
M3-2	EW	6.6679	10.09	0	0	0	0	0	0.00125	0
M3-3	EW	6.5718	9.02	0	0	0	0	0.005	0.01925	0.00375
M3-4	EW	6.554	8.88	0	0	0	0	0	0	0
M3-5	EW	6.5638	8.76	0	0	0	0	0	0.00025	0
M3-6	EW	6.5274	8.65	0	0	0	0	0	0	0
C3-1	EW	7.1403	33.7	0.2	0	0	0.0025	0	0	0
C3-2	EW	6.8866	15.03	0	0	0	0	0	0	0
C3-3	EW	6.6432	11.44	0	0	0	0	0	0	0
C3-4	EW	6.5888	10.51	0	0	0	0	0	0	0
C3-5	EW	6.5236	9.8	0	0	0	0	0	0	0
C3-6	EW	6.5203	9.8	0	0	0	0	0	0	0
A3-1	EW	6.9264	51.9	0.5	0	0	0	0.024	0	0
A3-2	EW	6.9661	19.6	0	0	0	0	0	0	0
A3-3	EW	6.9105	15.68	0	0	0	0	0	0	0
A3-4	EW	6.8266	14.05	0	0	0	0	0.006	0	0.00975
A3-5	EW	6.8211	13.51	0	0	0	0	0	0	0
A3-6	EW	6.819	13.13	0	0	0	0	0	0	0
M4-1	EW	7.4297	23.7	0.1	0	0	0	0	0	0
M4-2	EW	6.6549	10.1	0	0	0	0	0	0	0
M4-3	EW	6.5679	8.87	0	0	0	0	0	0	0

Sample ID	Orien-tation	pH	EC, μS/cm	NO3N, ppm	SAR	B, ppm	Fe, ppm	Cu, ppm	Zn, ppm	Mn, ppm
M4-4	EW	6.5158	8.56	0	0	0	0	0	0	0
M4-5	EW	6.4987	8.44	0	0	0	0	0	0.00225	0
M4-6	EW	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
C4-1	EW	7.2178	32.9	0.2	0	0	0	0	0	0
C4-2	EW	6.7541	12.99	0	0	0	0	0	0	0
C4-3	EW	6.581	10.95	0	0	0	0	0	0	0
C4-4	EW	6.5662	10.3	0	0	0	0	0	0	0
C4-5	EW	6.5058	9.8	0	0	0	0	0	0	0
C4-6	EW	6.5127	9.8	0	0	0	0	0	0	0
A4-1	EW	6.8627	74	0.7	0	0	0	0.043	0	0
A4-2	EW	6.961	23.9	0	0	0	0	0	0	0
A4-3	EW	6.8559	18.95	0	0	0	0	0	0	0
A4-4	EW	6.8234	16.15	0	0	0	0	0	0	0
A4-5	EW	6.9138	23.5	0	0	0	0	0	0	0
A4-6	EW	7.0219	25.9	0	0	0	0	0	0	0
M6-1	EW	7.1163	29.3	0.1	0	0	0	0	0	0
M6-2	EW	6.9424	20.5	0	0	0	0	0	0	0
M6-3	EW	6.8781	19.11	0	0	0	0	0	0	0
M6-4	EW	6.8442	20.8	0	0	0	0	0	0	0
M6-5	EW	6.8317	18.3	0	0	0	0	0	0	0
M6-6	EW	6.8503	17.82	0	0	0	0	0	0	0
C6-1	EW	7.201	42.9	0.4	0	0	0	0	0	0
C6-2	EW	6.8605	20.8	0	0	0	0	0	0	0
C6-3	EW	6.8859	18.61	0	0	0	0	0	0	0
C6-4	EW	6.8022	18.53	0	0	0	0	0	0	0
C6-5	EW	6.7142	17.01	0	0	0	0	0	0	0
C6-6	EW	6.8094	17.31	0	0	0	0	0	0	0
A6-1	EW	7.1264	73.7	0.6	0	0	0	0.031	0	0
A6-2	EW	7.0065	28.8	0	0	0	0	0.005	0	0
A6-3	EW	6.8364	25	0	0	0	0	0	0	0
A6-4	EW	7.0166	23.1	0	0	0	0	0	0	0
A6-5	EW	7.0221	22.7	0	0	0	0	0	0	0
A6-6	EW	6.9427	22.2	0	0	0	0	0	0	0

Replicates and Field Blanks from Simulation Events

Results for NO3N, SAR, B, Fe, Cu, Zn, and Mn); Zero (0) indicates <Detection Limit

Simulation	Sample ID	Type	pH	EC, µS/cm	NO3N, ppm	SAR	B, ppm	Fe, ppm	Cu, ppm	Zn, ppm	Mn, ppm
August	A1-5R	Replicate	6.7318	39.2	0.2	0.4	0.1	0.01	0.01	0.02	0
August	A5-5R	Replicate	7.0049	38.5	0.1	0.4	0.1	0.01	0.01	0	0
August	C1-1R	Replicate	6.8424	91.6	1.8	0.3	0.1	0.02	0	0.04	
August	A3-1R	Replicate	6.5974	194.7	2.6	0.3	0.3	0.13	0.18	0.09	0.13
August	A6-4R	Replicate	6.9854	44.4	0.2	0.3	0.1	0.01	0.01	0	0
August	C3-3R	Replicate	7.0374	40.4	0.2	0.4	0.1	0.01	0	0	0
August	C6-5R	Replicate	7.2974	38.1	0.2	0.3	0.1	0	0	0	0
August	M3-2R	Replicate	7.1542	44.1	0.2	0.3	0.1	0.01	0	0.01	0
August	M4-1R	Replicate	7.1215	93.1	1.9	0.2	0.1	0.02	0	0.06	0
August	M6-6R	Replicate	7.3463	35	0.1	0.4	0.1	0	0	0	0
August	M1-2R	Replicate	7.0954	43.4	0.2	0.3	0.1	0.01	0	0.01	0
August	S-M (8/31) Morning	Field Blank	7.332	34.9	0.1	0.3	0.1	0	0	0	0
August	S-A (8/31) Afternoon	Field Blank	7.2991	34.4	0.2	0.4	0.1	0.01	0	0	0
August	S-M2 (8/30) Afternoon	Field Blank	7.1546	35	0.1	0.4	0.1	0	0	0	0
November	S-M 11/16 Morning	Field Blank	7.1478	20.8	0.2	0.4	0.1	0.04	0	0	0
November	S-A 11/16 Afternoon	Field Blank	7.165	21.5	0.2	0.4	0.1	0.06	0	0.01	0
November	S-M 11/17 Morning	Field Blank	7.1538	21.1	0.2	0.4	0.1	0.03	0	0	0
November	S -M2 11/17 Morning	Field Blank	7.1397	21.1	0.2	0.4	0.1	0.05	0	0.01	0
February	S-M 2/1 Morning	Field Blank	6.2327	7.57	0.2	1.2	0.1	0.02	0	0.04	0.01
February	S-A 2/2 Afternoon	Field Blank	6.1802	7.27	0.2	2.2	0.1	0.01	0	0.02	0.01
February	S-M 2/2 Morning	Field Blank	6.7632	15.17	0.2	0.3	0.1	0.01	0	0	0
February	S -M2 2/2 Morning	Field Blank	6.9897	20	0.2	0.2	0.1	0.15	0	0.01	0.01

Simulation Intensity 64 mm/hr (August 2011)

Turbidity

Sample ID	**Turbidity, NTU**	**Sample ID**	**Turbidity, NTU**	**Sample ID**	**Turbidity, NTU**
A1-1	13.3	M1-1	6.12	C3-1	35.7
A1-2	0.78	M1-2	3.84	C3-2	3.35
A1-3	2.52	M1-3	1.68	C3-3	0.96
A1-4	1.74	M1-4	1.29	C3-4	2.135
A1-5	2.19	M1-5	1.14	C3-5	0.61
A1-6	0.61	M1-6	0.32	C3-6	0.53
A2-1	21	M2-1	2.26	C4-1	1.8
A2-2	13.7	M2-2	0.97	C4-2	1.01
A2-3	3.55	M2-3	0.47	C4-3	1.26
A2-4	1.44	M2-4	0.48	C4-4	0.5
A2-5	1.46	M2-5	1.3	C4-5	0.55
A2-6	0.85	M2-6	0.41	C4-6	0.69
A5-1	6.76	M5-1	3.66	C6-1	30.2
A5-2	3.97	M5-2	2.85	C6-2	1.93
A5-3	1.67	M5-3	2.97	C6-3	1.37
A5-4	2.54	M5-4	0.83	C6-4	0.58
A5-5	1.05	M5-5	0.71	C6-5	2.1
A5-6	0.84	M5-6	0.29	C6-6	0.41
C1-1	62.1	A3-1	100	M3-1	13.7
C1-2	0.81	A3-2	11.4	M3-2	3.29
C1-3	1.22	A3-3	1.32	M3-3	2.2
C1-4	0.31	A3-4	1.94	M3-4	0.72
C1-5	0.66	A3-5	0.93	M3-5	1.26
C1-6	0.26	A3-6	0.66	M3-6	0.45
C2-1	16.3	A4-1	5.36	M4-1	39.9
C2-2	0.39	A4-2	3.73	M4-2	2.46
C2-3	1.42	A4-3	3.94	M4-3	1.51
C2-4	0.38	A4-4	1.12	M4-4	0.88
C2-5	0.5	A4-5	2.92	M4-5	1.27
C2-6	0.46	A4-6	1.56	M4-6	0.43
C5-1	0.79	A6-1	4.54	M6-1	32.4
C5-2	0.82	A6-2	2.92	M6-2	1.13
C5-3	0.66	A6-3	2.81	M6-3	2.89
C5-4	0.98	A6-4	5.1	M6-4	0.86
C5-5	0.74	A6-5	1.75	M6-5	0.94
C5-6	0.45	A6-6	0.82	M6-6	0.39

Simulation Intensity 38 mm/hr (November 2011)

Turbidity

Sample ID	Turbidity, NTU	Sample ID	Turbidity, NTU	Sample ID	Turbidity, NTU
M2-1	9.41	M5-2	0.68	M4-3	1.69
M2-2	1.06	M5-3	1.01	M4-4	2.02
M2-3	0.88	M5-4	1.21	M4-5	2.51
M2-4	0.57	M5-5	0.58	M4-6	1.34
M2-5	0.55	M5-6	0.95	C4-1	25.2
M2-6	0.43	C5-1	7.33	C4-2	3.64
C2-1	2.95	C5-2	1.17	C4-3	1.91
C2-2	1.91	C5-3	3.19	C4-4	1.56
C2-3	2.02	C5-4	0.82	C4-5	1.2
C2-4	0.92	C5-5	0.85	C4-6	1.48
C2-5	1.54	C5-6	0.81	A4-1	14.8
C2-6	0.85	A5-1	5.95	A4-2	2.61
A2-1	7.14	A5-2	2.02	A4-3	3.03
A2-2	1.79	A5-3	1.15	A4-4	1.79
A2-3	2.21	A5-4	0.98	A4-5	1.31
A2-4	1.85	A5-5	1.09	A4-6	1.09
A2-5	2.33	A5-6	1.49	M6-1	23.8
A2-6	0.54	M3-1	18.3	M6-2	2.66
M1-1	14.7	M3-2	3.74	M6-3	1.35
M1-2	0.83	M3-3	7.9	M6-4	2.49
M1-3	1.98	M3-4	2.68	M6-5	1.04
M1-4	1.11	M3-5	1.27	M6-6	2.19
M1-5	0.88	M3-6	0.66	C6-1	24.1
M1-6	1.08	C3-1	26.2	C6-2	3.15
C1-1	4.19	C3-2	3.17	C6-3	2.25
C1-2	1.24	C3-3	1.82	C6-4	1.29
C1-3	1.49	C3-4	1.62	C6-5	1.83
C1-4	1.33	C3-5	1.5	C6-6	1
C1-5	0.56	C3-6	2.12	A6-1	18.3
C1-6	0.46	A3-1	6.45	A6-2	3.74
A1-1	11.6	A3-2	5.15	A6-3	2.72
A1-2	2.49	A3-3	0.88	A6-4	1.76
A1-3	1.21	A3-4	2.01	A6-5	1.27
A1-4	1.22	A3-5	1.72	A6-6	1.38
A1-5	1.16	A3-6	1.88		
A1-6	1.06	M4-1	37.5		
M5-1	1.5	M4-2	4.9		

Simulation Intensity 28 mm/hr (February 2012)

Turbidity

Sample ID	**Turbidity, NTU**	**Sample ID**	**Turbidity, NTU**	**Sample ID**	**Turbidity, NTU**
M2-1	0.86	M5-2	0.27	M4-3	0.26
M2-2	0.35	M5-3	0.3	M4-4	0.3
M2-3	0.28	M5-4	0.34	M4-5	0.33
M2-4	0.32	M5-5	0.24	M4-6	No Sample
M2-5	0.35	M5-6	0.38	C4-1	1.63
M2-6	0.23	C5-1	2.07	C4-2	0.43
C2-1	1.95	C5-2	0.37	C4-3	0.46
C2-2	0.84	C5-3	0.29	C4-4	0.28
C2-3	0.45	C5-4	0.3	C4-5	0.36
C2-4	0.46	C5-5	0.28	C4-6	0.37
C2-5	0.39	C5-6	0.24	A4-1	3.28
C2-6	0.3	A5-1	5.68	A4-2	1.73
A2-1	8.93	A5-2	2.58	A4-3	1.09
A2-2	2.08	A5-3	1.56	A4-4	0.73
A2-3	1.21	A5-4	0.5	A4-5	1.1
A2-4	0.67	A5-5	2	A4-6	0.98
A2-5	0.8	A5-6	0.59	M6-1	0.93
A2-6	1.14	M3-1	1.05	M6-2	0.44
M1-1	1.31	M3-2	0.39	M6-3	0.27
M1-2	0.36	M3-3	0.4	M6-4	0.32
M1-3	0.53	M3-4	0.26	M6-5	0.23
M1-4	0.36	M3-5	0.25	M6-6	0.2
M1-5	0.24	M3-6	0.2	C6-1	0.89
M1-6	0.29	C3-1	2.2	C6-2	0.44
C1-1	1.48	C3-2	0.73	C6-3	0.3
C1-2	0.53	C3-3	0.44	C6-4	0.33
C1-3	0.38	C3-4	0.41	C6-5	0.31
C1-4	0.28	C3-5	0.37	C6-6	0.52
C1-5	0.32	C3-6	0.39	A6-1	3.86
C1-6	0.33	A3-1	3.17	A6-2	0.78
A1-1	7.93	A3-2	1.59	A6-3	0.5
A1-2	1	A3-3	1.18	A6-4	0.44
A1-3	1.35	A3-4	0.88	A6-5	0.46
A1-4	1.25	A3-5	0.46	A6-6	0.4
A1-5	1.07	A3-6	0.86		
A1-6	1.01	M4-1	0.71		
M5-1	0.88	M4-2	0.32		

Replicates from Simulation Events

Turbidity

No turbidity replicates from August Simulation

Simulation	Sample ID	Reading 1 (NTU)	Reading 2 (NTU)	Reading 3 (NTU)	Reading 4 (NTU)	Reading 5 (NTU)	Median (NTU)
November	A2-5 R	1.04	0.78	0.73	0.85	0.709	0.78
November	C2-5 R	1.79	1.46	1.22	1.24	1.31	1.31
November	C5-2 R	1.55	2.05	1.62	1.81	1.59	1.62
November	M1-3 R	1.94	1.71	1.45	1.36	1.29	1.45
November	M2-5 R	0.7	0.76	1.29	0.63	0.61	0.7
November	M5-3 R	2.14	2.1	1.56	1.2	1.69	1.69
November	A4-1 R	14	13.9	14.3	14.1	13.5	14
November	A6-6 R	1.28	1.21	1.31	1.41	1.52	1.31
November	M4-2R	4.68	4.13	3.83	3.76	3.76	3.83
November	M6-4R	1.99	2.04	1.84	1.49	1.73	1.84
November	C3-4R	1.35	1.08	1.43	1.14	1.39	1.35
February	A5-1R	1.27	1.4	1.53	1.35	1.27	1.35
February	C3-2R	0.44	0.48	0.59	0.51	0.57	0.51
February	A4-6R	0.24	0.42	0.41	0.63	0.4	0.41
February	A3-2R	0.39	0.44	0.46	0.43	0.45	0.44
February	A1-2R	0.6	0.53	1.46	0.66	0.99	0.66
February	M3-4R	0.27	0.3	0.5	0.31	0.35	0.31
February	C6-1R	0.69	0.66	0.73	0.65	0.75	0.69
February	C5-3R	0.27	0.44	0.2	0.25	0.32	0.27
February	C2-5R	0.26	0.35	0.3	0.36	0.48	0.35
February	C4-5R	0.49	0.37	0.42	0.34	0.45	0.42
February	M1-4R	0.3	0.28	0.3	0.37	0.31	0.3

Simulation Intensity 64 mm/hr (August 2011)

Total Suspended Solids

No TSS data for this simulation event.

Simulation Intensity 38 mm/hr (November 2011)

Total Suspended Solids (TSS)

Sample ID	**TSS, mg/L**	**Sample ID**	**TSS, mg/L**	**Sample ID**	**TSS, mg/L**
M2-1	92.25	M5-1	65.25	M4-1	83.25
M2-2	3.25	M5-2	8.25	M4-2	11.25
M2-3	10.25	M5-3	8.25	M4-3	10.25
M2-4	5.25	M5-4	3.25	M4-4	2.25
M2-5	<1	M5-5	6.25	M4-5	3.25
M2-6	1.25	M5-6	1.25	M4-6	<1
C2-1	41.25	C5-1	60.25	C4-1	58.25
C2-2	17.25	C5-2	11.25	C4-2	10.25
C2-3	11.25	C5-3	8.25	C4-3	2.25
C2-4	5.25	C5-4	<1	C4-4	<1
C2-5	7.25	C5-5	<1	C4-5	5.25
C2-6	4.25	C5-6	<1	C4-6	4.25
A2-1	82.25	A5-1	50.25	A4-1	30.25
A2-2	21.25	A5-2	11.25	A4-2	4.25
A2-3	6.25	A5-3	2.25	A4-3	6.25
A2-4	4.25	A5-4	3.25	A4-4	8.25
A2-5	13.25	A5-5	1.25	A4-5	3.25
A2-6	<1	A5-6	5.25	A4-6	2.25
M1-1	45.25	M3-1	82.25	M6-1	61.25
M1-2	4.25	M3-2	11.25	M6-2	18.25
M1-3	6.25	M3-3	8.25	M6-3	6.25
M1-4	5.25	M3-4	<1	M6-4	8.25
M1-5	4.25	M3-5	2.25	M6-5	<1
M1-6	2.25	M3-6	<1	M6-6	4.25
C1-1	44.25	C3-1	68.25	C6-1	67.25
C1-2	3.25	C3-2	35.25	C6-2	8.25
C1-3	3.25	C3-3	3.25	C6-3	6.25
C1-4	6.25	C3-4	1.25	C6-4	6.25
C1-5	8.25	C3-5	<1	C6-5	2.25
C1-6	<1	C3-6	<1	C6-6	3.25
A1-1	39.25	A3-1	38.25	A6-1	33.25
A1-2	17.25	A3-2	6.25	A6-2	9.25
A1-3	7.25	A3-3	5.25	A6-3	11.25
A1-4	8.25	A3-4	5.25	A6-4	20.25
A1-5	9.25	A3-5	12.25	A6-5	5.25
A1-6	2.25	A3-6	1.25	A6-6	4.25

Simulation Intensity 28 mm/hr (February 2012)

Total Suspended Solids (TSS)

Sample ID	TSS, mg/L	Sample ID	TSS, mg/L	Sample ID	TSS, mg/L
M2-1	39.25	M5-2	7.25	M4-3	<1
M2-2	8.25	M5-3	<1	M4-4	<1
M2-3	1.25	M5-4	2.25	M4-5	2.25
M2-4	<1	M5-5	<1	M4-6	No Sample
M2-5	<1	M5-6	<1	C4-1	43.25
M2-6	<1	C5-1	48.25	C4-2	9.25
C2-1	48.25	C5-2	5.25	C4-3	<1
C2-2	16.25	C5-3	<1	C4-4	4.25
C2-3	1.25	C5-4	<1	C4-5	<1
C2-4	4.25	C5-5	<1	C4-6	<1
C2-5	1.25	C5-6	<1	A4-1	57.25
C2-6	2.25	A5-1	53.25	A4-2	14.25
A2-1	60.25	A5-2	11.25	A4-3	5.25
A2-2	9.25	A5-3	8.25	A4-4	6.25
A2-3	5.25	A5-4	2.25	A4-5	10.25
A2-4	4.25	A5-5	2.25	A4-6	2.25
A2-5	8.25	A5-6	1.25	M6-1	49.25
A2-6	<1	M3-1	20.25	M6-2	6.25
M1-1	56.25	M3-2	5.25	M6-3	3.25
M1-2	7.25	M3-3	1.25	M6-4	1.25
M1-3	1.25	M3-4	1.25	M6-5	1.25
M1-4	1.25	M3-5	<1	M6-6	<1
M1-5	1.25	M3-6	1.25	C6-1	65.25
M1-6	2.25	C3-1	32.25	C6-2	44.25
C1-1	22.25	C3-2	4.25	C6-3	<1
C1-2	3.25	C3-3	3.25	C6-4	<1
C1-3	3.25	C3-4	1.25	C6-5	2.25
C1-4	3.25	C3-5	<1	C6-6	<1
C1-5	<1	C3-6	<1	A6-1	89.25
C1-6	1.25	A3-1	53.25	A6-2	7.25
A1-1	61.25	A3-2	10.25	A6-3	7.25
A1-2	9.25	A3-3	10.25	A6-4	8.25
A1-3	7.25	A3-4	7.25	A6-5	4.25
A1-4	<1	A3-5	8.25	A6-6	1.25
A1-5	<1	A3-6	10.25		
A1-6	4.25	M4-1	31.25		
M5-1	63.25	M4-2	7.25		

Replicates from Simulation Events

Total Suspended Solids (TSS)

No Total Suspended Solids replicates from August Simulation

Simulation	Sample ID	TSS (mg/L)
November	Blank (RO)	1
November	Blank (RO)	0
November	Blank (RO)	0
November	Blank (RO)	0
November	Blank (RO)	0
November	A2-5R	11
November	A4-1R	30
November	A6-6R	2
November	C2-5R	7
November	C3-4R	6
November	C5-2R	10
November	M1-3R	11
November	M2-5R	5
November	M4-2R	16
November	M5-3R	1
November	M6-4R	2
February	Blank (RO)	0
February	Blank (RO)	0
February	Blank (RO)	0
February	Blank (RO)	0
February	Blank (RO)	0
February	Blank (RO)	0
February	A1-2R	12
February	A3-2 R	14
February	A4-6R	3
February	C2-5R	6
February	C3-2R	4
February	C4-5 R	5
February	C5-3R	4
February	M1-4R	4
February	M3-4R	2
February	M5-1 R	61

Simulation Intensity 64 mm/hr (August 2011)

Polycyclic Aromatic Hydrocarbons, Flame Retardants, and Pyrethroid Insecticide Results

			Asphalt Fraction 1, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	0	0	34	0	38	0
PAH	2-Methylnaphthalene	30	0	0	0	0	30	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	30	0	37	0
PAH	Fluorene	30	0	0	55	0	0	0
PAH	Phenanthrene	30	0	0	59	46	34	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	127	94	94	103	140	113
PAH	Pyrene	10	105	63	76	73	121	82
PAH	Benz(a)anthracene	10	37	30	25	26	44	37
PAH	Chrysene	10	98	65	71	78	114	87
PAH	Benzo(b)fluoranthene	10	135	55	99	103	173	121
PAH	Benzo(k)fluoranthene	10	68	82	58	55	86	64
PAH	Benzo(a)pyrene	10	93	46	52	54	90	60
PAH	Indeno(1,2,3-cd)pyrene	10	60	54	49	49	92	57
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	10	0
PAH	Benzo(g,h,i)perylene	10	34	27	25	23	51	25
PAH	Sum PAHs	>300	757	516	727	610	1060	646
PAH	Sum of Commonly Detected	>75	686	459	499	515	816	584
PAH	Sum of Probable Carcinogens	>70	491	332	354	365	609	426
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	93	61	42	46	46	33
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Asphalt Fraction 2, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	0	0	0	0	0	0
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	37	0	0	40
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	47	32	57	61	54	77
PAH	Pyrene	10	31	19	32	39	36	45
PAH	Benz(a)anthracene	10	11	0	11	14	14	18
PAH	Chrysene	10	24	15	23	29	25	35
PAH	Benzo(b)fluoranthene	10	21	11	18	24	23	30
PAH	Benzo(k)fluoranthene	10	10	0	0	10	11	11
PAH	Benzo(a)pyrene	10	15	10	13	18	17	20
PAH	Indeno(1,2,3-cd)pyrene	10	19	10	16	20	18	22
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	0	0	0	0	0	10
PAH	Sum PAHs	>300	178	97	207	215	198	308
PAH	Sum of Commonly Detected	>75	167	97	159	201	184	240
PAH	Sum of Probable Carcinogens	>70	100	46	81	115	108	136
Flame Retardant	TCEP	30						0
Flame Retardant	TDCPP	30	154	93	114	211	196	100
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Asphalt Fraction 3, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	48	52	0	0	0	0
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	22	19	18	27	13	36
PAH	Pyrene	10	15	11	11	17	13	26
PAH	Benz(a)anthracene	10	0	0	0	0	0	10
PAH	Chrysene	10	14	15	10	14	0	23
PAH	Benzo(b)fluoranthene	10	0	0	0	11	0	17
PAH	Benzo(k)fluoranthene	10	0	0	0	0	0	10
PAH	Benzo(a)pyrene	10	0	0	0	0	0	12
PAH	Indeno(1,2,3-cd)pyrene	10	0	0	0	0	0	16
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	0	0	0	0	0	0
PAH	Sum PAHs	>300	99	97	39	69	26	150
PAH	Sum of Commonly Detected	>75	51	45	39	69	26	140
PAH	Sum of Probable Carcinogens	>70	14	15	10	25	0	88
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	62	61	0	40	58	49
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Asphalt Fraction 6, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	0	0	0	0	0	0
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	21	0	22	19	20	24
PAH	Pyrene	10	11	0	12	0	0	21
PAH	Benz(a)anthracene	10	0	0	0	0	0	0
PAH	Chrysene	10	0	0	0	0	0	11
PAH	Benzo(b)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(k)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(a)pyrene	10	0	0	0	0	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	0	0	0	0	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	0	0	0	0	0	0
PAH	Sum PAHs	>300	32	0	34	19	20	56
PAH	Sum of Commonly Detected	>75	32	0	34	19	20	56
PAH	Sum of Probable Carcinogens	>70	0	0	0	0	0	11
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	39	34	0	28	42	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Metal Fraction 1, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	0	64	0	0	31	0
PAH	2-Methylnaphthalene	30	0	33	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	40	77	40	51	33	87
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	72	232	162	176	151	188
PAH	Pyrene	10	48	167	116	128	108	137
PAH	Benz(a)anthracene	10	31	47	51	43	33	41
PAH	Chrysene	10	72	128	88	192	90	99
PAH	Benzo(b)fluoranthene	10	77	146	96	137	77	125
PAH	Benzo(k)fluoranthene	10	48	116	67	90	63	82
PAH	Benzo(a)pyrene	10	46	118	84	97	76	95
PAH	Indeno(1,2,3-cd)pyrene	10	85	149	119	115	80	129
PAH	Dibenzo(a,h)anthracene	10	0	12	11	10	0	0
PAH	Benzo(g,h,i)perylene	10	54	86	63	59	45	79
PAH	Sum PAHs	>300	573	1375	897	1098	787	1062
PAH	Sum of Commonly Detected	>75	448	1056	732	935	645	855
PAH	Sum of Probable Carcinogens	>70	359	716	516	684	419	571
Flame Retardant	TCEP	30	32	0	0	0	0	0
Flame Retardant	TDCPP	30	40	74	66	53	56	59
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Metal Fraction 2, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	0	36	0	0	0	0
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	31	0	0	0	0
PAH	Phenanthrene	30	0	0	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	27	19	31	22	30	18
PAH	Pyrene	10	12	12	16	11	18	0
PAH	Benz(a)anthracene	10	0	0	0	0	0	0
PAH	Chrysene	10	0	0	0	0	10	0
PAH	Benzo(b)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(k)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(a)pyrene	10	0	0	0	0	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	0	0	0	0	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	0	0	0	0	0	0
PAH	Sum PAHs	>300	39	98	47	33	58	18
PAH	Sum of Commonly Detected	>75	39	31	47	33	58	18
PAH	Sum of Probable Carcinogens	>70	0	0	0	0	10	0
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	121	89	70	102	139	105
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Metal Fraction 3, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	0	52	0	41	49	0
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	0	0	0	0	0	0
PAH	Pyrene	10	0	0	0	0	0	0
PAH	Benz(a)anthracene	10	0	0	0	0	0	0
PAH	Chrysene	10	0	0	0	0	0	0
PAH	Benzo(b)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(k)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(a)pyrene	10	0	0	0	0	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	0	0	0	0	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	0	0	0	0	0	0
PAH	Sum PAHs	>300	0	52	0	41	49	0
PAH	Sum of Commonly Detected	>75	0	0	0	0	0	0
PAH	Sum of Probable Carcinogens	>70	0	0	0	0	0	0
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	44	32	0	35	47	35
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Metal Fraction 6, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	42	0	0	0	0	31
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	16	0	0	0	0	0
PAH	Pyrene	10	0	0	0	0	0	0
PAH	Benz(a)anthracene	10	0	0	0	0	0	0
PAH	Chrysene	10	0	0	0	0	0	0
PAH	Benzo(b)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(k)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(a)pyrene	10	0	0	0	0	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	0	0	0	0	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	0	0	0	0	0	0
PAH	Sum PAHs	>300	58	0	0	0	0	31
PAH	Sum of Commonly Detected	>75	16	0	0	0	0	0
PAH	Sum of Probable Carcinogens	>70	0	0	0	0	0	0
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	0	0	0	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Clay Fraction 1, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	0	45	0	36	0	0
PAH	2-Methylnaphthalene	30	0	32	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	31	0	31	90	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	135	164	83	217	95	95
PAH	Pyrene	10	95	121	55	151	64	60
PAH	Benz(a)anthracene	10	30	39	0	45	69	66
PAH	Chrysene	10	75	91	40	135	45	44
PAH	Benzo(b)fluoranthene	10	68	102	45	134	47	46
PAH	Benzo(k)fluoranthene	10	58	65	31	92	30	29
PAH	Benzo(a)pyrene	10	69	77	38	112	44	42
PAH	Indeno(1,2,3-cd)pyrene	10	60	103	48	137	50	48
PAH	Dibenzo(a,h)anthracene	10	0	11	0	12	0	0
PAH	Benzo(g,h,i)perylene	10	44	66	29	81	32	32
PAH	Sum PAHs	>300	665	916	400	1242	476	462
PAH	Sum of Commonly Detected	>75	560	723	340	978	375	364
PAH	Sum of Probable Carcinogens	>70	360	488	202	667	285	275
Flame Retardant	TCEP	30	39	0	30	30	32	43
Flame Retardant	TDCPP	30	215	58	61	72	77	84
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Clay Fraction 2, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	0	38	0	0	0	0
PAH	2-Methylnaphthalene	30	0	32	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	18	22	16	17	34	0
PAH	Pyrene	10	10	10	0	9	20	0
PAH	Benz(a)anthracene	10	0	0	0	0	0	0
PAH	Chrysene	10	0	0	0	0	0	0
PAH	Benzo(b)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(k)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(a)pyrene	10	0	0	0	0	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	0	0	0	0	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	0	0	0	0	0	0
PAH	Sum PAHs	>300	28	102	16	26	54	0
PAH	Sum of Commonly Detected	>75	28	32	16	26	54	0
PAH	Sum of Probable Carcinogens	>70	0	0	0	0	0	0
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	141	146	72	104	111	58
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Clay Fraction 3, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	120	0	0	0	143	0
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	0	0	0	0	0	0
PAH	Pyrene	10	0	0	0	0	0	0
PAH	Benz(a)anthracene	10	0	0	0	0	0	0
PAH	Chrysene	10	0	0	0	0	0	0
PAH	Benzo(b)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(k)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(a)pyrene	10	0	0	0	0	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	0	0	0	0	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	0	0	0	0	0	0
PAH	Sum PAHs	>300	120	0	0	0	143	0
PAH	Sum of Commonly Detected	>75	0	0	0	0	0	0
PAH	Sum of Probable Carcinogens	>70	0	0	0	0	0	0
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	47	39	0	34	34	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Clay Fraction 6, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	0	32	0	0	0	0
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	0	0	0	0	0	0
PAH	Pyrene	10	0	0	0	0	0	0
PAH	Benz(a)anthracene	10	0	0	0	0	0	0
PAH	Chrysene	10	0	0	0	0	0	0
PAH	Benzo(b)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(k)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(a)pyrene	10	0	0	0	0	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	0	0	0	0	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	0	0	0	0	0	0
PAH	Sum PAHs	>300	0	32	0	0	0	0
PAH	Sum of Commonly Detected	>75	0	0	0	0	0	0
PAH	Sum of Probable Carcinogens	>70	0	0	0	0	0	0
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	33	0	0	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

Simulation Intensity 38 mm/hr (November 2011)

Polycyclic Aromatic Hydrocarbons, Flame Retardants, and Pyrethroid Insecticide Results

			Asphalt Fraction 1, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	32	0	41	44	0	47
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	30	0	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	33	46	36	27	27	24
PAH	Pyrene	10	24	33	34	19	20	17
PAH	Benz(a)anthracene	10	0	0	0	0	0	0
PAH	Chrysene	10	17	20	19	15	13	14
PAH	Benzo(b)fluoranthene	10	23	29	33	31	21	22
PAH	Benzo(k)fluoranthene	10	14	18	14	15	12	10
PAH	Benzo(a)pyrene	10	19	23	22	22	16	17
PAH	Indeno(1,2,3-cd)pyrene	10	25	26	22	18	18	13
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	18	17	14	10	11	10
PAH	Sum PAHs	>300	205	212	265	201	138	174
PAH	Sum of Commonly Detected	>75	155	195	180	147	127	117
PAH	Sum of Probable Carcinogens	>70	98	116	110	101	80	76
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	0	0	0	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Asphalt Fraction 2, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	0	41	0	0	0	0
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	0	0	15	0	0	0
PAH	Pyrene	10	0	0	0	0	0	0
PAH	Benz(a)anthracene	10	0	0	0	0	0	0
PAH	Chrysene	10	0	0	0	0	0	0
PAH	Benzo(b)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(k)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(a)pyrene	10	0	0	0	0	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	13	11	12	0	12	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	0	0	0	0	0	0
PAH	Sum PAHs	>300	13	52	27	0	12	0
PAH	Sum of Commonly Detected	>75	13	11	27	0	12	0
PAH	Sum of Probable Carcinogens	>70	13	11	12	0	12	0
Flame Retardant	TCEP	30						0
Flame Retardant	TDCPP	30	0	0	0	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Asphalt Fraction 3, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	0	0	0	0	0	0
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	0	0	0	0	0	0
PAH	Pyrene	10	0	0	0	0	0	0
PAH	Benz(a)anthracene	10	0	0	0	0	0	0
PAH	Chrysene	10	0	0	0	0	0	0
PAH	Benzo(b)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(k)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(a)pyrene	10	0	0	0	0	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	0	0	0	0	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	0	0	0	0	0	0
PAH	Sum PAHs	>300	0	0	0	0	0	0
PAH	Sum of Commonly Detected	>75	0	0	0	0	0	0
PAH	Sum of Probable Carcinogens	>70	0	0	0	0	0	0
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	0	0	0	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Asphalt Fraction 6, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	0	0	0	0	0	0
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	0	0	0	0	20	33
PAH	Pyrene	10	0	0	0	0	15	28
PAH	Benz(a)anthracene	10	0	0	0	0	0	0
PAH	Chrysene	10	0	0	0	0	0	10
PAH	Benzo(b)fluoranthene	10	0	0	0	0	14	23
PAH	Benzo(k)fluoranthene	10	0	0	0	0	11	11
PAH	Benzo(a)pyrene	10	0	0	0	0	12	13
PAH	Indeno(1,2,3-cd)pyrene	10	0	0	0	0	11	12
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	0	0	0	0	12	11
PAH	Sum PAHs	>300	0	0	0	0	95	141
PAH	Sum of Commonly Detected	>75	0	0	0	0	83	130
PAH	Sum of Probable Carcinogens	>70	0	0	0	0	48	69
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	0	0	0	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Metal Fraction 1, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	0	47	43	43	0	35
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	31	37	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	20	52	50	62	16	31
PAH	Pyrene	10	15	37	37	44	12	23
PAH	Benz(a)anthracene	10	0	0	0	0	0	13
PAH	Chrysene	10	0	20	19	22	0	11
PAH	Benzo(b)fluoranthene	10	11	28	32	36	10	16
PAH	Benzo(k)fluoranthene	10	10	22	20	25	0	12
PAH	Benzo(a)pyrene	10	10	23	25	29	10	15
PAH	Indeno(1,2,3-cd)pyrene	10	14	39	41	46	11	24
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	18	42	44	48	14	25
PAH	Sum PAHs	>300	98	310	342	392	73	205
PAH	Sum of Commonly Detected	>75	80	221	224	264	59	132
PAH	Sum of Probable Carcinogens	>70	45	132	137	158	31	91
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	0	0	0	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Metal Fraction 2, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	0	0	0	0	0	0
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	0	0	0	0	0	0
PAH	Pyrene	10	0	0	0	0	0	0
PAH	Benz(a)anthracene	10	0	0	0	0	0	0
PAH	Chrysene	10	0	0	0	0	0	0
PAH	Benzo(b)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(k)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(a)pyrene	10	0	0	0	0	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	0	0	0	0	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	0	0	0	0	0	0
PAH	Sum PAHs	>300	0	0	0	0	0	0
PAH	Sum of Commonly Detected	>75	0	0	0	0	0	0
PAH	Sum of Probable Carcinogens	>70	0	0	0	0	0	0
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	0	0	0	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Metal Fraction 3, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	0	0	0	0	0	0
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	0	0	0	0	0	0
PAH	Pyrene	10	0	0	0	0	0	0
PAH	Benz(a)anthracene	10	0	0	0	0	0	0
PAH	Chrysene	10	0	0	0	0	0	0
PAH	Benzo(b)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(k)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(a)pyrene	10	0	0	0	0	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	0	0	0	0	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	0	0	0	0	0	0
PAH	Sum PAHs	>300	0	0	0	0	0	0
PAH	Sum of Commonly Detected	>75	0	0	0	0	0	0
PAH	Sum of Probable Carcinogens	>70	0	0	0	0	0	0
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	62	61	0	40	58	49
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Metal Fraction 6, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	0	0	0	0	0	0
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	0	0	0	0	0	0
PAH	Pyrene	10	0	0	0	0	0	0
PAH	Benz(a)anthracene	10	0	0	0	0	0	0
PAH	Chrysene	10	0	0	0	0	0	0
PAH	Benzo(b)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(k)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(a)pyrene	10	0	0	0	0	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	0	0	0	0	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	0	0	0	0	0	0
PAH	Sum PAHs	>300	0	0	0	0	0	0
PAH	Sum of Commonly Detected	>75	0	0	0	0	0	0
PAH	Sum of Probable Carcinogens	>70	0	0	0	0	0	0
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	0	0	0	0	0	41
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Clay Fraction 1, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	31	0	41	45	0	54
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	33	0	34	33	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	52	18	40	32	34	23
PAH	Pyrene	10	38	12	27	23	24	15
PAH	Benz(a)anthracene	10	0	0	0	0	0	0
PAH	Chrysene	10	20	0	13	12	13	0
PAH	Benzo(b)fluoranthene	10	32	10	23	20	20	11
PAH	Benzo(k)fluoranthene	10	22	0	15	14	15	0
PAH	Benzo(a)pyrene	10	28	10	19	18	17	12
PAH	Indeno(1,2,3-cd)pyrene	10	43	13	26	27	22	13
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	46	12	26	33	25	14
PAH	Sum PAHs	>300	205	75	264	257	170	142
PAH	Sum of Commonly Detected	>75	155	63	163	146	145	74
PAH	Sum of Probable Carcinogens	>70	145	33	96	91	87	36
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	0	0	0	46	46	33
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Clay Fraction 2, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	44	53	41	0	0	35
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	0	0	15	0	0	0
PAH	Pyrene	10	0	0	0	0	0	0
PAH	Benz(a)anthracene	10	0	0	0	0	0	0
PAH	Chrysene	10	0	0	0	0	0	0
PAH	Benzo(b)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(k)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(a)pyrene	10	0	0	0	0	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	0	11	0	0	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	0	0	0	0	0	0
PAH	Sum PAHs	>300	44	64	56	0	0	35
PAH	Sum of Commonly Detected	>75	0	11	15	0	0	0
PAH	Sum of Probable Carcinogens	>70	0	11	0	0	0	0
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	0	0	0	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Clay Fraction 3, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	0	0	0	35	0	38
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	0	0	0	0	0	0
PAH	Pyrene	10	0	0	0	0	0	0
PAH	Benz(a)anthracene	10	0	0	0	0	0	0
PAH	Chrysene	10	0	0	0	0	0	0
PAH	Benzo(b)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(k)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(a)pyrene	10	0	0	0	0	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	0	0	0	0	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	0	0	0	0	0	0
PAH	Sum PAHs	>300	0	0	0	35	0	38
PAH	Sum of Commonly Detected	>75	0	0	0	0	0	0
PAH	Sum of Probable Carcinogens	>70	0	0	0	0	0	0
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	0	0	0	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Clay Fraction 6, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	0	0	37	120	33	35
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	0	0	0	0	0	0
PAH	Pyrene	10	0	0	0	0	0	0
PAH	Benz(a)anthracene	10	0	0	0	0	0	0
PAH	Chrysene	10	0	0	0	0	0	0
PAH	Benzo(b)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(k)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(a)pyrene	10	0	0	0	0	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	0	0	0	0	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	0	0	0	0	0	0
PAH	Sum PAHs	>300	0	0	37	120	33	35
PAH	Sum of Commonly Detected	>75	0	0	0	0	0	0
PAH	Sum of Probable Carcinogens	>70	0	0	0	0	0	0
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	0	0	0	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

Simulation Intensity 28 mm/hr (February 2012)

Polycyclic Aromatic Hydrocarbons, Flame Retardants, and Pyrethroid Insecticide Results

			Asphalt Fraction 1, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	90	90	61	81	88	103
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	66	77	62	86	65	73
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	111	119	110	128	106	124
PAH	Pyrene	10	81	97	81	94	83	87
PAH	Benz(a)anthracene	10	32	28	34	35	27	33.5
PAH	Chrysene	10	65	68	59	79	58	71
PAH	Benzo(b)fluoranthene	10	82	78	63	97	50	65
PAH	Benzo(k)fluoranthene	10	45	31	35	43	27	35
PAH	Benzo(a)pyrene	10	53	50	40	61	40	50
PAH	Indeno(1,2,3-cd)pyrene	10	71	96	89	86	102	117
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	11	12
PAH	Benzo(g,h,i)perylene	10	47	75	71	67	81	84
PAH	Sum PAHs	>300	743	809	705	857	738	854.5
PAH	Sum of Commonly Detected	>75	508	539	477	588	466	549
PAH	Sum of Probable Carcinogens	>70	348	351	320	401	315	383.5
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	0	0	0	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Asphalt Fraction 2, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	43	66	48	87	104	58
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	30	36	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	24	19	35	48	26	26
PAH	Pyrene	10	17	12	24	37	20	19
PAH	Benz(a)anthracene	10	0	0	0	13	0	0
PAH	Chrysene	10	10	0	17	27	13	11
PAH	Benzo(b)fluoranthene	10	10	0	20	26	11	17
PAH	Benzo(k)fluoranthene	10	0	0	14	14	12	0
PAH	Benzo(a)pyrene	10	0	0	11	19	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	10	16	22	26	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	0	10	16	19	0	0
PAH	Sum PAHs	>300	114	123	237	352	186	131
PAH	Sum of Commonly Detected	>75	71	47	143	197	82	73
PAH	Sum of Probable Carcinogens	>70	30	16	84	125	36	28
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	0	0	0	0	0	0
Pyrethroid	Bifenthrin	10	0	43	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Asphalt Fraction 3, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	100	65	80	92.3	65	98
PAH	2-Methylnaphthalene	30	0	0	81	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	0	16	22	18	16	0
PAH	Pyrene	10	0	10	16	12	10	0
PAH	Benz(a)anthracene	10	0	0	0	0	0	0
PAH	Chrysene	10	0	0	11	11	0	0
PAH	Benzo(b)fluoranthene	10	0	11	14	12	10	0
PAH	Benzo(k)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(a)pyrene	10	0	0	0	0	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	11	0	11	10	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	0	0	0	0	0	0
PAH	Sum PAHs	>300	111	102	235	155.3	101	98
PAH	Sum of Commonly Detected	>75	11	37	74	63	36	0
PAH	Sum of Probable Carcinogens	>70	11	11	36	33	10	0
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	0	0	0	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Asphalt Fraction 6, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	43	34	46	55	38	
PAH	2-Methylnaphthalene	30	0	0	0	0	0	
PAH	Acenaphthylene	30	0	0	0	0	0	
PAH	Acenaphthene	30	0	0	0	0	0	
PAH	Fluorene	30	0	0	0	0	0	
PAH	Phenanthrene	30	0	0	35	32	0	
PAH	Anthracene	15	0	0	0	0	0	
PAH	Fluoranthene	15	0	0	0	11	0	
PAH	Pyrene	10	0	0	0	0	0	
PAH	Benz(a)anthracene	10	0	0	0	0	0	
PAH	Chrysene	10	0	0	0	0	0	
PAH	Benzo(b)fluoranthene	10	0	0	0	0	0	
PAH	Benzo(k)fluoranthene	10	0	0	0	0	0	
PAH	Benzo(a)pyrene	10	0	0	0	0	0	
PAH	Indeno(1,2,3-cd)pyrene	10	0	0	0	0	0	
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	
PAH	Benzo(g,h,i)perylene	10	0	0	0	0	0	
PAH	Sum PAHs	>300	43	34	81	98	38	0
PAH	Sum of Commonly Detected	>75	0	0	0	11	0	0
PAH	Sum of Probable Carcinogens	>70	0	0	0	0	0	0
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	0	0	0	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Metal Fraction 1, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	67	89	78	95	49	108
PAH	2-Methylnaphthalene	30	0	30	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	48	46	36	34	50	52
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	82	53	57	53	86	78
PAH	Pyrene	10	57	37	40	36	60	54
PAH	Benz(a)anthracene	10	19	13	16	15	24	67
PAH	Chrysene	10	41	25	28	26	44	41
PAH	Benzo(b)fluoranthene	10	49	27	39	38	57	102
PAH	Benzo(k)fluoranthene	10	23	15	14	17	32	64
PAH	Benzo(a)pyrene	10	33	15	23	17	33	32
PAH	Indeno(1,2,3-cd)pyrene	10	58	25	38	29	46	38
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	27	14	17	14	19	18
PAH	Sum PAHs	>300	504	389	386	374	500	654
PAH	Sum of Commonly Detected	>75	343	197	239	216	358	409
PAH	Sum of Probable Carcinogens	>70	223	120	158	142	236	344
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	0	0	0	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Metal Fraction 2, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	59	80	34	47	44	35
PAH	2-Methylnaphthalene	30	0	30	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	0	15	0	0	0	0
PAH	Pyrene	10	0	10	0	0	0	0
PAH	Benz(a)anthracene	10	0	0	0	0	0	0
PAH	Chrysene	10	0	0	0	0	0	0
PAH	Benzo(b)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(k)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(a)pyrene	10	0	0	0	0	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	0	0	0	0	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	0	0	0	0	0	0
PAH	Sum PAHs	>300	59	135	34	47	44	35
PAH	Sum of Commonly Detected	>75	0	25	0	0	0	0
PAH	Sum of Probable Carcinogens	>70	0	0	0	0	0	0
Flame Retardant	TCEP	30						0
Flame Retardant	TDCPP	30	0	0	0	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Metal Fraction 3, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	98	112	70	70	59	56
PAH	2-Methylnaphthalene	30	0	42	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	0	0	0	0	0	0
PAH	Pyrene	10	0	0	0	0	0	0
PAH	Benz(a)anthracene	10	0	0	0	0	0	0
PAH	Chrysene	10	0	0	0	0	0	0
PAH	Benzo(b)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(k)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(a)pyrene	10	0	0	0	0	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	0	0	0	0	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	0	0	0	0	0	0
PAH	Sum PAHs	>300	98	154	70	70	59	56
PAH	Sum of Commonly Detected	>75	0	0	0	0	0	0
PAH	Sum of Probable Carcinogens	>70	0	0	0	0	0	0
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	0	0	0	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Metal Fraction 6, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	0	62	45	0	47	43
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	0	0	0	0	0	0
PAH	Pyrene	10	0	0	0	0	0	0
PAH	Benz(a)anthracene	10	0	0	0	0	0	0
PAH	Chrysene	10	0	0	0	0	0	0
PAH	Benzo(b)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(k)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(a)pyrene	10	0	0	0	0	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	0	0	0	0	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	0	0	0	0	0	0
PAH	Sum PAHs	>300	0	62	45	0	47	43
PAH	Sum of Commonly Detected	>75	0	0	0	0	0	0
PAH	Sum of Probable Carcinogens	>70	0	0	0	0	0	0
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	0	0	0	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Clay Fraction 1, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	56	115	90	82	108	94
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	47	53	46	40	71	65
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	70	93	78	57	127	105
PAH	Pyrene	10	50	68	59	41	94	75
PAH	Benz(a)anthracene	10	21	25	17	13	34	26
PAH	Chrysene	10	34	46	40	29	61	52
PAH	Benzo(b)fluoranthene	10	43	58	48	44	82	61
PAH	Benzo(k)fluoranthene	10	21	37	23	19	39	29
PAH	Benzo(a)pyrene	10	25	38	35	20	51	43
PAH	Indeno(1,2,3-cd)pyrene	10	42	45	39	21	67	60
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	28	29	29	14	49	42
PAH	Sum PAHs	>300	437	607	504	380	783	652
PAH	Sum of Commonly Detected	>75	285	385	322	231	521	425
PAH	Sum of Probable Carcinogens	>70	186	249	202	146	334	271
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	0	0	0	0	0	33
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Clay Fraction 2, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	61	76	53	34	69	57
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	0	0	15	0	0	0
PAH	Pyrene	10	0	0	10	0	0	0
PAH	Benz(a)anthracene	10	0	0	0	0	0	0
PAH	Chrysene	10	0	0	0	0	0	0
PAH	Benzo(b)fluoranthene	10	0	13	0	0	0	0
PAH	Benzo(k)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(a)pyrene	10	0	0	0	0	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	0	0	0	0	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	0	0	0	0	0	0
PAH	Sum PAHs	>300	61	89	78	34	69	57
PAH	Sum of Commonly Detected	>75	0	13	25	0	0	0
PAH	Sum of Probable Carcinogens	>70	0	13	0	0	0	0
Flame Retardant	TCEP	30						0
Flame Retardant	TDCPP	30	0	0	0	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Clay Fraction 3, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	71	74	43	63	37	32
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	0	0	0	0	0	0
PAH	Pyrene	10	0	0	0	0	0	0
PAH	Benz(a)anthracene	10	0	0	0	0	0	0
PAH	Chrysene	10	0	0	0	0	0	0
PAH	Benzo(b)fluoranthene	10	0	0	11	0	0	0
PAH	Benzo(k)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(a)pyrene	10	0	0	0	0	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	0	0	0	0	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	0	0	0	0	0	0
PAH	Sum PAHs	>300	71	74	54	63	37	32
PAH	Sum of Commonly Detected	>75	0	0	11	0	0	0
PAH	Sum of Probable Carcinogens	>70	0	0	11	0	0	0
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	0	0	0	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			Clay Fraction 6, ng/L					
Class		RL, ng/L	1	2	3	4	5	6
PAH	Naphthalene	30	86	64	70	60	32	33
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	0	0	0	0	0	0
PAH	Pyrene	10	0	0	0	0	0	0
PAH	Benz(a)anthracene	10	0	0	0	0	0	0
PAH	Chrysene	10	0	0	0	0	0	0
PAH	Benzo(b)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(k)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(a)pyrene	10	0	0	0	0	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	0	0	0	0	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	0	0	0	0	0	0
PAH	Sum PAHs	>300	86	64	70	60	32	33
PAH	Sum of Commonly Detected	>75	0	0	0	0	0	0
PAH	Sum of Probable Carcinogens	>70	0	0	0	0	0	0
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	0	0	0	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

Polycyclic Aromatic Hydrocarbons, Flame Retardants, and Pyrethroid Insecticide Results from Field Blanks

Class		RL, ng/L	sm 830	sm 831	sma 831	sm 1117	sa 1116	sa 1117	sm 1116	sm 0201	sm 0202	Blank 0201	Blank 0203
PAH	Naphthalene	30	35	0	0	0	0	0	0	69	79	41	42
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	0	0	0	0	0	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0	0	0	0	0	0	0
PAH	Fluoranthene	15	0	0	0	0	0	0	0	0	0	0	0
PAH	Pyrene	10	0	0	0	0	0	0	0	0	0	0	0
PAH	Benz(a)anthracene	10	0	0	0	0	0	0	0	0	0	0	0
PAH	Chrysene	10	0	0	0	0	0	0	0	0	0	0	0
PAH	Benzo(b)fluoranthene	10	0	0	0	0	0	0	0	0	0	0	0
PAH	Benzo(k)fluoranthene	10	0	0	0	0	0	0	0	0	0	0	0
PAH	Benzo(a)pyrene	10	0	0	0	0	0	0	0	0	0	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	0	0	0	0	0	0	0	0	0	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	0	0	0	0	0	0	0	0	0	0	0
Flame Retardant	TCEP	30	0	0	0	0	0	0	0	0	0	0	0
Flame Retardant	TDCPP	30	0	0	0	0	0	0	0	0	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0	0	0	0	0	0

Polycyclic Aromatic Hydrocarbons, Flame Retardants, and Pyrethroid Insecticide Matrix Recoveries

Asphalt 4 Sample 6 Matrix Spike					
		Sample	Spike Concentration	a46ms	
Class		Conc.		Spike	**%**
PAH	Naphthalene	0	52	100	**52**
PAH	2-Methylnaphthalene	0	53	100	**53**
PAH	Acenaphthylene	0	46	100	**46**
PAH	Acenaphthene	0	49	100	**49**
PAH	Fluorene	0	60	100	**60**
PAH	Phenanthrene	0	86	100	**86**
PAH	Anthracene	0	64	100	**64**
PAH	Fluoranthene	6	93	100	**87**
PAH	Pyrene	0	90	100	**90**
PAH	Benz(a)anthracene	0	85	100	**85**
PAH	Chrysene	0	71	100	**71**
PAH	Benzo(b)fluoranthene	4	104	100	**100**
PAH	Benzo(k)fluoranthene	4	103	100	**99**
PAH	Benzo(a)pyrene	0	86	100	**86**
PAH	Indeno(1,2,3-cd)pyrene	0	71	100	**71**
PAH	Dibenzo(a,h)anthracene	0	75	100	**75**
PAH	Benzo(g,h,i)perylene	0	85	100	**85**
Flame Retardant	TCEP	0	--	100	**--**
Flame Retardant	TDCPP	0	--	100	**--**
Pyrethroid	Bifenthrin	0	48	100	**48**
Pyrethroid	Cypermethrin	0	103	100	**103**
Pyrethroid	Lambda-cyhalothrin	0	72	100	**72**

Asphalt 4 Sample 6 Matrix Spike Duplicate					
		Sample	Spike Concentration	a46msd	
Class		Conc.		Spike	**%**
PAH	Naphthalene	0	54	100	**54**
PAH	2-Methylnaphthalene	0	62	100	**62**
PAH	Acenaphthylene	0	55	100	**55**
PAH	Acenaphthene	0	57	100	**57**
PAH	Fluorene	0	71	100	**71**
PAH	Phenanthrene	0	112	100	**112**
PAH	Anthracene	0	77	100	**77**
PAH	Fluoranthene	6	109	100	**103**
PAH	Pyrene	0	106	100	**106**
PAH	Benz(a)anthracene	0	68	100	**68**
PAH	Chrysene	0	71	100	**71**
PAH	Benzo(b)fluoranthene	4	121	100	**117**
PAH	Benzo(k)fluoranthene	4	107	100	**103**
PAH	Benzo(a)pyrene	0	96	100	**96**
PAH	Indeno(1,2,3-cd)pyrene	0	59	100	**59**
PAH	Dibenzo(a,h)anthracene	0	66	100	**66**
PAH	Benzo(g,h,i)perylene	0	73	100	**73**
Flame Retardant	TCEP	0	--	100	**--**
Flame Retardant	TDCPP	0	--	100	**--**
Pyrethroid	Bifenthrin	0	53	100	**53**
Pyrethroid	Cypermethrin	0	110	100	**110**
Pyrethroid	Lambda-cyhalothrin	0	76	100	**76**

Clay 6 Sample 6 Matrix Spike					
		Sample	Spike Concentration	c66ms	
Class		Conc.		Spike	**%**
PAH	Naphthalene	0	65	100	**65**
PAH	2-Methylnaphthalene	0	71	100	**71**
PAH	Acenaphthylene	0	57	100	**57**
PAH	Acenaphthene	0	70	100	**70**
PAH	Fluorene	0	66	100	**66**
PAH	Phenanthrene	0	83	100	**83**
PAH	Anthracene	0	74	100	**74**
PAH	Fluoranthene	6	88	100	**82**
PAH	Pyrene	0	85	100	**85**
PAH	Benz(a)anthracene	0	105	100	**105**
PAH	Chrysene	0	95	100	**95**
PAH	Benzo(b)fluoranthene	4	99	100	**95**
PAH	Benzo(k)fluoranthene	4	101	100	**97**
PAH	Benzo(a)pyrene	0	69	100	**69**
PAH	Indeno(1,2,3-cd)pyrene	0	93	100	**93**
PAH	Dibenzo(a,h)anthracene	0	92	100	**92**
PAH	Benzo(g,h,i)perylene	0	77	100	**77**
Flame Retardant	TCEP	0	0	100	**--**
Flame Retardant	TDCPP	0	0	100	**--**
Pyrethroid	Bifenthrin	0	118	100	**118**
Pyrethroid	Cypermethrin	0	120	100	**120**
Pyrethroid	Lambda-cyhalothrin	0	112	100	**112**

Clay 6 Sample 6 Matrix Spike Duplicate					
		Samp le	Spike Concentration	c66ms d	
Class		Conc.		Spike	**%**
PAH	Naphthalene	0	95	100	**95**
PAH	2-Methylnaphthalene	0	95	100	**95**
PAH	Acenaphthylene	0	102	100	**102**
PAH	Acenaphthene	0	99	100	**99**
PAH	Fluorene	0	105	100	**105**
PAH	Phenanthrene	0	143	100	**143**
PAH	Anthracene	0	104	100	**104**
PAH	Fluoranthene	6	135	100	**129**
PAH	Pyrene	0	135	100	**135**
PAH	Benz(a)anthracene	0	143	100	**143**
PAH	Chrysene	0	131	100	**131**
PAH	Benzo(b)fluoranthene	4	134	100	**130**
PAH	Benzo(k)fluoranthene	4	134	100	**130**
PAH	Benzo(a)pyrene	0	136	100	**136**
PAH	Indeno(1,2,3-cd)pyrene	0	85	100	**85**
PAH	Dibenzo(a,h)anthracene	0	88	100	**88**
PAH	Benzo(g,h,i)perylene	0	121	100	**121**
Flame Retardant	TCEP	0		100	**--**
Flame Retardant	TDCPP	0		100	**--**
Pyrethroid	Bifenthrin	0	99	100	**99**
Pyrethroid	Cypermethrin	0	137	100	**137**
Pyrethroid	Lambda-cyhalothrin	0	132	100	**132**

Metal 4 Sample 6 Matrix Spike					
		Sample	Spike Concentration	46ms	
Class		Conc.		Spike	**%**
PAH	Naphthalene	0	68	100	**68**
PAH	2-Methylnaphthalene	0	67	100	**67**
PAH	Acenaphthylene	0	65	100	**65**
PAH	Acenaphthene	0	71	100	**71**
PAH	Fluorene	0	84	100	**84**
PAH	Phenanthrene	0	127	100	**127**
PAH	Anthracene	0	95	100	**95**
PAH	Fluoranthene	6	124	100	**118**
PAH	Pyrene	0	127	100	**127**
PAH	Benz(a)anthracene	0	133	100	**133**
PAH	Chrysene	0	114	100	**114**
PAH	Benzo(b)fluoranthene	4	99	100	**95**
PAH	Benzo(k)fluoranthene	4	105	100	**101**
PAH	Benzo(a)pyrene	0	77	100	**77**
PAH	Indeno(1,2,3-cd)pyrene	0	92	100	**92**
PAH	Dibenzo(a,h)anthracene	0	95	100	**95**
PAH	Benzo(g,h,i)perylene	0	90	100	**90**
Flame Retardant	TCEP	0		100	**--**
Flame Retardant	TDCPP	0		100	**--**
Pyrethroid	Bifenthrin	0	128	100	**128**
Pyrethroid	Cypermethrin	0	105	100	**105**
Pyrethroid	Lambda-cyhalothrin	0	126	100	**126**

Metal 4 Sample 6 Matrix Spike Duplicate					
		Sampl e	Spike Concentration	46msd	
Class		Conc.		Spike	**%**
PAH	Naphthalene	0	55	100	**55**
PAH	2-Methylnaphthalene	0	48	100	**48**
PAH	Acenaphthylene	0	44	100	**44**
PAH	Acenaphthene	0	47	100	**47**
PAH	Fluorene	0	51	100	**51**
PAH	Phenanthrene	0	64	100	**64**
PAH	Anthracene	0	63	100	**63**
PAH	Fluoranthene	6	65	100	**59**
PAH	Pyrene	0	64	100	**64**
PAH	Benz(a)anthracene	0	71	100	**71**
PAH	Chrysene	0	70	100	**70**
PAH	Benzo(b)fluoranthene	4	76	100	**72**
PAH	Benzo(k)fluoranthene	4	80	100	**76**
PAH	Benzo(a)pyrene	0	62	100	**62**
PAH	Indeno(1,2,3-cd)pyrene	0	84	100	**84**
PAH	Dibenzo(a,h)anthracene	0	81	100	**81**
PAH	Benzo(g,h,i)perylene	0	85	100	**85**
Flame Retardant	TCEP	0		100	**--**
Flame Retardant	TDCPP	0		100	**--**
Pyrethroid	Bifenthrin	0	90	100	**90**
Pyrethroid	Cypermethrin	0	84	100	**84**
Pyrethroid	Lambda-cyhalothrin	0	80	100	**80**

Overall Averages from all matrix samples			
Class		average	SD
PAH	Naphthalene	65	16.1
PAH	2-Methylnaphthalene	66	16.6
PAH	Acenaphthylene	62	21.3
PAH	Acenaphthene	66	19.3
PAH	Fluorene	73	19.2
PAH	Phenanthrene	103	29.9
PAH	Anthracene	80	16.7
PAH	Fluoranthene	96	25.6
PAH	Pyrene	101	26.8
PAH	Benz(a)anthracene	101	31.8
PAH	Chrysene	92	26.0
PAH	Benzo(b)fluoranthene	102	20.0
PAH	Benzo(k)fluoranthene	101	17.3
PAH	Benzo(a)pyrene	88	26.6
PAH	Indeno(1,2,3-cd)pyrene	81	13.2
PAH	Dibenzo(a,h)anthracene	83	11.0
PAH	Benzo(g,h,i)perylene	89	17.1
Flame Retardant	TCEP		
Flame Retardant	TDCPP		
Pyrethroid	Bifenthrin	89	33.0
Pyrethroid	Cypermethrin	110	17.8
Pyrethroid	Lambda-cyhalothrin	100	26.8

Polycyclic Aromatic Hydrocarbons, Flame Retardants, and Pyrethroid Insecticide Quad Study

		August 11 Quad Study							
Compound	Blank 081111	Q1		Q2		Q3		Q4	
Naphthalene	0	189.12	**94.56**	194.64	**97.32**	186.31	**93.155**	182.69	**91.345**
2-Methylnaphthalene	0	155.86	**77.93**	166.7	**83.35**	155.85	**77.925**	147.93	**73.965**
Acenaphthylene	0	188.9	**94.45**	188.62	**94.31**	167.03	**83.515**	151.9	**75.95**
Acenaphthene	0	192.28	**96.14**	204.79	**102.395**	184.07	**92.035**	169.26	**84.63**
Fluorene	0	214.57	**107.285**	211.45	**105.725**	210.33	**105.165**	197.3	**98.65**
Phenanthrene	0	268	**134**	265	**132.5**	250	**125**	205	**102.5**
Anthracene	0	152.32	**76.16**	156.06	**78.03**	161.27	**80.635**	149.22	**74.61**
Fluoranthene	0	212	**106**	202	**101**	216	**108**	208	**104**
Pyrene	0	226.42	**113.21**	216.83	**108.415**	228.42	**114.21**	220.63	**110.315**
Benz(a)anthracene	0	176.23	**88.115**	173.06	**86.53**	190.13	**95.065**	183.39	**91.695**
Chrysene	0	171.51	**85.755**	162.83	**81.415**	190.76	**95.38**	189.97	**94.985**
Benzo(b)fluoranthene	0	176.41	**88.205**	178.25	**89.125**	192.13	**96.065**	187.59	**93.795**
Benzo(k)fluoranthene	0	186.93	**93.465**	180.87	**90.435**	191.23	**95.615**	177.85	**88.925**
Benzo(a)pyrene	0	148.92	**74.46**	145.57	**72.785**	147.78	**73.89**	127.11	**63.555**
Indeno(1,2,3-cd)pyrene	0	209.26	**104.63**	205.42	**102.71**	204.78	**102.39**	189.02	**94.51**
Dibenzo(a,h)anthracene	0	248.37	**124.185**	239.44	**119.72**	239.63	**119.815**	213.75	**106.875**
Benzo(g,h,i)perylene	0	254.12	**127.06**	225.89	**112.945**	249.47	**124.735**	218.04	**109.02**
TCEP	0	362.38	**181.19**	326.93	**163.465**	303.67	**151.835**	290.12	**145.06**
TDCPP	0	480.52	**240.26**	452.59	**226.295**	450.84	**225.42**	428.94	**214.47**
Bifenthrin	0	253.6	**126.8**	229.39	**114.695**	222.94	**111.47**	210.92	**105.46**
L-cyhalothrin	0	196.56	**98.28**	168.82	**84.41**	170.42	**85.21**	153.05	**76.525**
Cypermethrin 1	0	255.3	**127.65**	151.27	**75.635**	258.75	**129.375**	238.09	**119.045**
p-Terphenyl d14		158.16	**79.08**	175.22	**87.61**	182.79	**91.395**	179.52	**89.76**

Compound	blnk 0201	0201 LS		0201 LSD			Overall Average	SD
Naphthalene	41	190	149	181	140		110.90	26.26
2-Methylnaphthalene		128	128	117	117		93.03	23.28
Acenaphthylene		138	138	129	129		102.54	25.14
Acenaphthene		132	132	115	115		103.70	17.25
Fluorene		117	117	118	118		108.64	7.48
Phenanthrene	6	115	109	108	102		117.50	14.77
Anthracene		77	77	79	79		77.57	2.13
Fluoranthene		67	67	68	68		92.33	19.38
Pyrene		59	59	63	63		94.69	26.21
Benz(a)anthracene		57	57	62	62		80.07	16.28
Chrysene		55	55	70	70		80.42	15.62
Benzo(b)fluoranthene		77	77	73	73		86.20	9.24
Benzo(k)fluoranthene		85	85	73	73		87.74	8.10
Benzo(a)pyrene		65	65	59	59		68.12	6.47
Indeno(1,2,3-cd)pyrene		74	74	78	78		92.71	13.46
Dibenzo(a,h)anthracene		80	80	71	71		103.60	22.70
Benzo(g,h,i)perylene		88	88	85	85		107.79	17.88
TCEP							160.39	15.81
TDCPP		110	110	109	109		187.57	61.03
Bifenthrin		130	130	77	77		110.90	19.03
L-cyhalothrin		78	78	74	74		82.74	8.81
Cypermethrin 1							112.93	25.27
p-Terphenyl d14		70	70	85	85		83.81	8.02

Surrogate Recoveries from Organics Testing of Rainfall Simulation Samples

*From analysis of stock solution against curve; Average recovery 86.3% ± 21.7%

Sample Event	column/fraction		p-terph	exp*	%
1	a1	1	121	110	110
1	a2	1	90	110	81.81818
1	a3	1	126	110	114.5455
1	a4	1	122	110	110.9091
1	a5	1	116	110	105.4545
1	a6	1	88	110	80
1	m12	1	68	110	61.81818
1	m22	1	120	110	109.0909
1	m32	1	75	110	68.18182
1	m42	1	105	110	95.45455
1	m52	1	106	110	96.36364
1	m62	1	108	110	98.18182
1	c1	1	85	110	77.27273
1	c2	1	118	110	107.2727
1	c3	1	93	110	84.54545
1	c4	1	129	110	117.2727
1	c5	1	103	110	93.63636
1	c6	1	73	110	66.36364
1	a1	2	80	110	72.72727
1	a2	2	60	110	54.54545
1	a3	2	90	110	81.81818
1	a4	2	140	110	127.2727
1	a5	2	105	110	95.45455
1	a6	2	85	110	77.27273
1	m12	2	110	110	100
1	m22	2	105	110	95.45455
1	m32	2	110	110	100
1	m42	2	110	110	100
1	m52	2	145	110	131.8182
1	m62	2	85	110	77.27273
1	c1	2	134	110	121.8182
1	c2	2	125	110	113.6364
1	c3	2	95	110	86.36364
1	c4	2	150	110	136.3636
1	c5	2	135	110	122.7273
1	c6	2	75	110	68.18182
1	a1	6	141	140	100.7143
1	a2	6	132	140	94.28571
1	a3	6	112	140	80

1	a4	6	118	140	84.28571
1	a5	6	116	140	82.85714
1	a6	6	98	140	70
1	m1	6	130	140	92.85714
1	m2	6	138	140	98.57143
1	m3	6	115	140	82.14286
1	m4	6	103	140	73.57143
1	m5	6	133	140	95
1	m6	6	114	140	81.42857
1	c1	6	114	140	81.42857
1	c2	6	169	140	120.7143
1	c3	6	151	140	107.8571
1	c4	6	137	140	97.85714
1	c5	6	176	140	125.7143
1	c6	6	146	140	104.2857
1	a1	3	79	100	79
1	a2	3	94	100	94
1	a3	3	59	100	59
1	a4	3	66	100	66
1	a5	3	59	100	59
1	a6	3	95	100	95
1	m1	3	96	100	96
1	m2	3	77	100	77
1	m3	3	71	100	71
1	m4	3	82	100	82
1	m5	3	59	100	59
1	m6	3	61	100	61
1	c1	3	90	100	90
1	c2	3	61	100	61
1	c3	3	80	100	80
1	c4	3	79	100	79
1	c5	3	73	100	73
1	c6	3	65	100	65
2	a1	1	38	65	58.46154
2	a2	1	41	65	63.07692
2	a3	1	60	65	92.30769
2	a4	1	59	65	90.76923
2	a5	1	na	65	
2	a6	1	66	65	101.5385
2	m12	1	na	65	
2	m22	1	42	65	64.61538
2	m32	1	68	65	104.6154
2	m42	1	74	65	113.8462
2	m52	1	60	65	92.30769
2	m62	1	68	65	104.6154
2	c1	1	46	65	70.76923

2	c2	1	44	65	67.69231
2	c3	1	82	65	126.1538
2	c4	1	80	65	123.0769
2	c5	1	48	65	73.84615
2	c6	1	64	65	98.46154
2	a1	2	43	65	66.15385
2	a2	2	54	65	83.07692
2	a3	2	na	65	
2	a4	2	66	65	101.5385
2	a5	2	55	65	84.61538
2	a6	2	66	65	101.5385
2	m12	2	40	65	61.53846
2	m22	2	na	65	
2	m32	2	77	65	118.4615
2	m42	2	56	65	86.15385
2	m52	2	40	65	61.53846
2	m62	2	48	65	73.84615
2	c1	2	84	65	129.2308
2	c2	2	53	65	81.53846
2	c3	2	62	65	95.38462
2	c4	2	58	65	89.23077
2	c5	2	56	65	86.15385
2	c6	2	60	65	92.30769
2	a1	6	51	65	78.46154
2	a2	6	na	65	
2	a3	6	65	65	100
2	a4	6	52	65	80
2	a5	6	37	65	56.92308
2	a6	6	41	65	63.07692
2	m1	6	54	65	83.07692
2	m2	6	na	65	
2	m3	6	65	65	100
2	m4	6	74	65	113.8462
2	m5	6	78	65	120
2	m6	6	67	65	103.0769
2	c1	6	49	65	75.38462
2	c2	6	na	65	
2	c3	6	78	65	120
2	c4	6	81	65	124.6154
2	c5	6	69.4	65	106.7692
2	c6	6	45	65	69.23077
2	a1	3	52.9	65	81.38462
2	a2	3	48.6	65	74.76923
2	a3	3	45.1	65	69.38462
2	a4	3	37.6	65	57.84615
2	a5	3	37.3	65	57.38462

2	a6	3	27.3	65	42
2	m1	3	51.5	65	79.23077
2	m2	3	42.8	65	65.84615
2	m3	3	54.7	65	84.15385
2	m4	3	57.4	65	88.30769
2	m5	3	60.5	65	93.07692
2	m6	3	37.9	65	58.30769
2	c1	3	32.2	65	49.53846
2	c2	3	33.4	65	51.38462
2	c3	3	25.3	65	38.92308
2	c4	3	65.7	65	101.0769
2	c5	3	42.6	65	65.53846
2	c6	3	35	65	53.84615
3	a1	1	62	65	95.38462
3	a2	1	54	65	83.07692
3	a3	1	52	65	80
3	a4	1	57	65	87.69231
3	a5	1	58	65	89.23077
3	a6	1	62	65	95.38462
3	m1	1	42	65	64.61538
3	m2	1	38	65	58.46154
3	m3	1	50	65	76.92308
3	m4	1	45	65	69.23077
3	m5	1	44	65	67.69231
3	m6	1	41	65	63.07692
3	c1	1	50	65	76.92308
3	c2	1	62	65	95.38462
3	c3	1	53	65	81.53846
3	c4	1	52	65	80
3	c5	1	70	65	107.6923
3	c6	1	67	65	103.0769
3	a1	2	45	65	69.23077
3	a2	2	44	65	67.69231
3	a3	2	41	65	63.07692
3	a4	2	39.6	65	60.92308
3	a5	2	60	65	92.30769
3	a6	2	52	65	80
3	m12	2	56	65	86.15385
3	m22	2	84	65	129.2308
3	m32	2	40	65	61.53846
3	m42	2	64	65	98.46154
3	m52	2	80	65	123.0769
3	m62	2	35	65	53.84615
3	c1	2	70	65	107.6923
3	c2	2	51	65	78.46154
3	c3	2	63	65	96.92308

3	c4	2	26	65	40
3	c5	2	63	65	96.92308
3	c6	2	63	65	96.92308
3	a1	6	47	65	72.30769
3	a2	6	43	65	66.15385
3	a3	6	88	65	135.3846
3	a4	6	62	65	95.38462
3	a5	6	42	65	64.61538
3	a6	6	45	65	69.23077
3	m1	6	36	65	55.38462
3	m2	6	55	65	84.61538
3	m3	6	37	65	56.92308
3	m4	6	109	65	167.6923
3	m5	6	47	65	72.30769
3	m6	6	60	65	92.30769
3	c1	6	66.9	65	102.9231
3	c2	6	76	65	116.9231
3	c3	6	62	65	95.38462
3	c4	6	77	65	118.4615
3	c5	6	45	65	69.23077
3	c6	6	80	65	123.0769
3	a1	3	52.9	55	96.18182
3	a2	3	48.6	55	88.36364
3	a3	3	45.1	55	82
3	a4	3	37.6	55	68.36364
3	a5	3	37.3	55	67.81818
3	a6	3	35.3	55	64.18182
3	m1	3	51.5	55	93.63636
3	m2	3	42.8	55	77.81818
3	m3	3	54.7	55	99.45455
3	m4	3	57.4	55	104.3636
3	m5	3	70.5	55	128.1818
3	m6	3	37.9	55	68.90909
3	c1	3	32.2	55	58.54545
3	c2	3	33.4	55	60.72727
3	c3	3	32.3	55	58.72727
3	c4	3	65.7	55	119.4545
3	c5	3	42.6	55	77.45455
3	c6	3	35	55	63.63636

APPENDIX B

WATER QUALITY RESULTS FOR OKLAHOMA CITY FIELD SAMPLES:

OKC Metal Roof (OSU-OKC Horticulture Pavilion, HP): pH, EC, NO_3-N, SAR, B, Fe, Cu, Zn, Mn (N.S. = No Sample)

Date	ADP (Days)	Sample	Runoff Volume (L)	Runoff Depth (mm)	Total Storm Volume (L)	pH	EC, µS/cm	NO3N, ppm	SAR	B, ppm	Fe, ppm	Cu, ppm	Zn, ppm	Mn, ppm	TSS, mg/L	Turbidity, NTU	Total Coliforms CFU/100 mL	E. coli CFU/100 mL
4/3/2012	11	HP-1	108	1.23	870	6.9764	26	0.3	0	0	0.02	0	0.04	0	41	5.81	N.S.	N.S.
4/3/2012	11	HP-2	112	1.27	870	7.027	22.3	0.3	0	0	0.03	0	0.02	0	17	3.81	N.S.	N.S.
4/3/2012	11	HP-3	116	1.32	870	6.8465	19.9	0	0	0	0.03	0	0	0	12	1.34	N.S.	N.S.
4/3/2012	11	HP-5	461	5.25	870	6.8617	17.21	0.2	0	0	0.02	0	0	0	36	10.6	N.S.	N.S.
4/3/2012	11	HP-6	856	9.75	870	6.6859	13.45	0.2	0	0	0.02	0	0	0	8	1.2	N.S.	N.S.
4/11/2012	7	HP-1	93.0	1.06	93.0	6.9695	25.4	0.4	0.1	0	0.03	0	0.01	0	16	3.78	N.S.	N.S.
4/13/2012	1	HP-1	128.9	1.47	1291.0	6.538	26.4	0.5	0.2	0	0.02	0.01	0	0	17	5.01	N.S.	N.S.
4/13/2012	1	HP-2	132.8	1.51	1291.0	6.408	20.8	0.4	0.1	0	0.02	0	0	0	13	1.81	N.S.	N.S.
4/13/2012	1	HP-5	1074.0	12.23	1291.0	6.2152	13.96	0.2	0.1	0	0.02	0	0	0	11	1.61	N.S.	N.S.
4/19/2012	3	HP-1	91.0	1.04	339.0	7.3497	42.2	0.6	0.1	0	0.02	0	0	0	11	4.04	N.S.	N.S.
4/19/2012	3	HP-2	130.0	1.48	339.0	6.9999	30.9	0.4	0.1	0	0.03	0	0	0	8	2.75	N.S.	N.S.
4/19/2012	3	HP-3	200.0	2.28	339.0	6.8271	21.7	0.3	0.1	0	0.03	0	0	0	8	1.68	N.S.	N.S.
4/28/2012	8	HP-1	91.0	1.04	189.0	7.3672	62.4	0.8	0.2	0	0	0	0	0	43	22.9	N.S.	N.S.
4/28/2012	8	HP-3	96.0	1.09	189.0	7.2642	56.4	0.8	0.2	0	0	0	0	0	6	13.4	N.S.	N.S.
4/28/2012	8	HP-4	115.0	1.31	189.0	7.3213	60.2	0.9	0.2	0	0	0	0	0	45	26.4	N.S.	N.S.
5/20/2012	6	HP-1	71.0	0.81	359.0	7.1527	42.1	0.7	0.1	0	0.03	0	0	0	36	17.4	N.S.	N.S.
5/20/2012	6	HP-2	85.0	0.97	359.0	7.0963	31.4	0.5	0.1	0	0.03	0	0	0	37	15.7	N.S.	N.S.
5/20/2012	6	HP-3	129.0	1.47	359.0	6.999	24.8	0.5	0.1	0	0.02	0	0	0	21	12.3	N.S.	N.S.
5/20/2012	6	HP-4	188.0	2.14	359.0	6.9055	20.9	0.4	0.1	0	0.02	0	0	0	15	7.04	N.S.	N.S.
5/20/2012	6	HP-5	318.0	3.62	359.0	6.8559	25.6	0.6	0.1	0	0.02	0	0	0	9	6.45	N.S.	N.S.
5/20/2012	6	HP-6	359.0	4.09	359.0	6.8743	24.9	0.6	0.1	0	0.03	0	0	0	7	5.49	N.S.	N.S.
5/29/2012	6	HP-1	40.0	0.46	347.4	6.831	36.6	0.7	0.1	0	0.03	0	0	0	23	11.8	100	0
6/6/2012	2	HP-1	86.0	0.98	764.0	6.6656	24.4	0.6	0.1	0	0.02	0.01	0.02	0	27	10.8	2030	0
6/6/2012	2	HP-2	157.0	1.79	764.0	6.3265	21.1	0.5	0.1	0	0.02	0	0.01	0	9	4.77	1350	0
6/6/2012	2	HP-3	323.0	3.68	764.0	6.3393	15.84	0.4	0.1	0	0.01	0	0	0	2	2.55	860	0
6/6/2012	2	HP-4	457.0	5.21	764.0	6.0711	13.74	0.4	0.1	0	0.02	0	0.02	0	1	1.84	1610	0
6/6/2012	2	HP-5	650.0	7.40	764.0	6.2331	27.2	0.8	0.1	0	0.02	0	0.01	0	1	2.87	56.8	1
6/6/2012	2	HP-6	745.0	8.49	764.0	6.0446	33.7	1	0.1	0	0.02	0	0.02	0	4	4.44	69.9	0
6/15/2012	7	HP-1	141.0	1.61	2285.0	6.6821	36	0.3	0.5	0	0.03	0	0.01	0	25	8.51	91.2	1
6/15/2012	7	HP-2	224.0	2.55	2285.0	6.3626	19.44	0.3	0.4	0	0.03	0	0.01	0	9	4.74	86.2	2
6/15/2012	7	HP-3	398.0	4.53	2285.0	6.3269	15.12	0.4	0.3	0	0.03	0	0.01	0	10	4.45	1100	0
6/15/2012	7	HP-4	672.0	7.65	2285.0	6.3672	10.49	0.3	0.2	0	0.02	0	0	0	7	4.84	520	0
6/15/2012	7	HP-5	1761.0	20.06	2285.0	6.0486	8.15	0.3	0.3	0	0.03	0	0	0	5	2.65	860	0
6/15/2012	7	HP-6	2284.6	26.02	2285.0	6.0429	9.52	0.4	0.3	0	0.03	0	0.01	0	7	3.57	520	0
7/9/2012	17	HP-1	29.6	0.34	70.0	6.774	149.8	1	0.9	0	0.02	0	0	0	34	15.1	100	0
7/9/2012	17	HP-2	37.0	0.42	70.0	6.7766	153.6	1	0.9	0	0.02	0	0.02	0	23	13.7	310	0
7/9/2012	17	HP-3	40.9	0.47	70.0	6.8256	55.8	0.8	0.2	0	0.02	0	0.01	0	34	16.3	0	0
7/9/2012	17	HP-4	59.1	0.67	70.0	6.6672	48.1	0.7	0.2	0	0.02	0	0.01	0	16	9.56	200	0
7/9/2012	17	HP-5	67.0	0.76	70.0	6.6542	52.7	0.7	0.3	0	0.02	0	0.01	0	14	8.57	300	0

OKC Asphalt Shingle Roof (AS)

pH, EC, NO_3-N, SAR, B, Fe, Cu, Zn, Mn, TSS, Turbidity, Total Coliforms, and *E. coli*

Date	ADP (Days)	Sample	Runoff Volume (L)	Runoff Depth (mm)	Total Storm Volume (L)	pH	EC, µS/cm	NO3N, ppm	SAR	B, ppm	Fe, ppm	Cu, ppm	Zn, ppm	Mn, ppm	TSS, mg/L	Turbidity, NTU	Total Coliforms CFU/100 mL	*E. coli* CFU/100 mL
4/11/2012	7	AS-1	5.5	0.59	36.7	7.3814	129.4	1.6	0.2	0.1	0.02	0.05	0.01	0	49	20.1	N.S.	N.S.
4/13/2012	1	AS-1	5.5	0.59	152.6	7.4382	121.3	0.9	0.3	0.1	0.02	0.05	0	0.01	16	9.73	N.S.	N.S.
4/13/2012	1	AS-3	16.5	1.77	152.6	7.1149	40.1	0.4	0.1	0	0.03	0.01	0	0	18	3.37	N.S.	N.S.
4/13/2012	1	AS-4	23.9	2.57	152.6	7.0728	30.3	0.3	0.1	0	0.02	0	0	0	20	2.4	N.S.	N.S.
4/19/2012	3	AS-1	7.4	0.79	64.4	7.36	87.3	0.3	0.1	0	0.03	0.02	0	0.01	48	3.85	N.S.	N.S.
4/19/2012	3	AS-2	20.2	2.17	64.4	7.2095	63.3	0.5	0.1	0	0.03	0.01	0	0.01	51	3.48	N.S.	N.S.
4/19/2012	3	AS-3	29.4	3.16	64.4	7.1187	40.1	0.5	0.1	0	0.02	0	0	0	28	2.22	N.S.	N.S.
5/11/2012	9	AS-1	5.5	0.59	29.4	7.1363	146.1	2	0.2	0.1	0.1	0.07	0.02	0.1	27	13.5	N.S.	N.S.
5/29/2012	6	AS-1	14.1	1.52	144.3	7.1654	67.9	0.8	0.1	0	0.03	0.01	0	0	56	33.7	365.4	0
5/29/2012	6	AS-2	35.4	3.80	144.3	6.9415	28.5	0.5	0	0	0.03	0	0	0	54	15.6	2010	100
5/29/2012	6	AS-3	70.5	7.58	144.3	6.6866	20.9	0.4	0	0	0.02	0	0	0	28	8.03	686.7	0
5/29/2012	6	AS-4	110.7	11.90	144.3	6.695	22.7	0.5	0.1	0	0.03	0	0	0	13	6.67	2149.2	34.5
5/29/2012	6	AS-5	115.5	12.42	144.3	6.7785	25	0.5	0.1	0	0.03	0	0	0	11	6.54	2419.2	24.3
6/6/2012	2	AS-1	9.2	0.99	64.4	6.8523	67.7	1	0.1	0	0.03	0.02	0	0	35	14.9	1732.87	33.2
6/6/2012	2	AS-2	20.2	2.17	64.4	6.8387	29.4	0.6	0.1	0	0.03	0	0	0.07	33	13.8	980	0
6/6/2012	2	AS-3	34.9	3.76	64.4	6.0739	22.1	0.5	0.1	0	0.02	0	0	0	22	8.53	310	0
6/6/2012	2	AS-4	48.1	5.17	64.4	6.6547	21.6	0.4	0.1	0	0.02	0	0	0	11	4.57	100	0
6/6/2012	2	AS-5	52.9	5.68	64.4	6.7601	22.7	0.4	0.1	0	0.02	0	0	0	6	4.03	310	0
6/6/2012	2	AS-6	64.4	6.93	64.4	6.9995	41.9	1	0.1	0	0.02	0	0	0	7	6.31	310	0
7/9/2012	17	AS-1	14.7	1.58	20.2	6.5979	167.7	1.2	0.5	0.1	0.05	0.05	0.03	0.15	85	36.2	100	0
7/9/2012	17	AS-4	20.2	2.17	20.2	6.6607	109.9	1	0.3	0	0.04	0.03	0.01	0.02	34	18.7	630	0

N.S. = No Sample

OKC Tar and Gravel Roof (OSU-OKC Maintenance Shop, MS)

pH, EC, NO_3-N, SAR, B, Fe, Cu, Zn, Mn, TSS, Turbidity, Total Coliforms, and E. coli

Date	**ADP (Days)**	**Sample**	**Runoff Volume (L)**	**Runoff Depth (mm)**	**Total Storm Volume (L)**	**pH**	**EC, µS/cm**	**NO3N, ppm**	**SAR**	**B, ppm**	**Fe, ppm**	**Cu, ppm**	**Zn, ppm**	**Mn, ppm**	**TSS, mg/L**	**Turbidity, NTU**	**Total Coliforms CFU/100 mL**	***E. coli* CFU/100 mL**
4/11/2012	7	MS-1	34.7	0.38	43.5	7.0486	41.3	0.7	0.1	0	0.03	0.02	0.12	0	12	10.8	N.S.	N.S.
4/11/2012	7	MS-2	40.7	0.44	43.5	6.9576	41	0.7	0.1	0	0.03	0.01	0.03	0	8	10	N.S.	N.S.
4/13/2012	1	MS-1	64.3	0.70	1058.3	7.1254	48.5	0.7	0.1	0	0.04	0	0.01	0	15	8.95	N.S.	N.S.
4/13/2012	1	MS-2	97.2	1.05	1058.3	7.1442	46.7	0.7	0.1	0	0.04	0	0.01	0	14	5.6	N.S.	N.S.
4/13/2012	1	MS-3	132.7	1.44	1058.3	7.156	46.3	0.7	0.1	0	0.04	0	0.01	0	11	6.69	N.S.	N.S.
4/19/2012	3	MS-2	92.2	1.00	97.2	7.0989	44.5	0.6		0	0.03	0	0	0	11	3.8	N.S.	N.S.
4/28/2012	8	MS-1	5.4	0.06	124.8	7.6346	122	1.3	0.2	0	0	0	0	0	25	18.5	N.S.	N.S.
4/28/2012	8	MS-3	44.2	0.48	124.8	7.5084	103.7	1.5	0.1	0	0	0	0	0	9	11.3	N.S.	N.S.
4/28/2012	8	MS-4	72.0	0.78	124.8	7.4576	104.2	1.5	0.1	0	0	0	0	0	5	11.2	N.S.	N.S.
5/20/2012	6	MS-1	8.4	0.09	111.5	7.265	72.5	1.2	0.1	0	0.05	0.04	0.05	0	25	18.6	N.S.	N.S.
5/20/2012	6	MS-2	51.6	0.56	111.5	7.1993	61.4	1.1	0.1	0	0.04	0	0.03	0	16	16.6	N.S.	N.S.
5/20/2012	6	MS-3	108.7	1.18	111.5	7.1425	56.8	1	0.1	0	0.04	0	0.03	0	12	13.1	N.S.	N.S.
5/29/2012	6	MS-1	58.5	0.63	236.8	6.9236	33.5	0.6	0	0	0.04	0.01	0.24	0	66	24.4	275.5	108.1
5/29/2012	6	MS-2	216.0	2.34	236.8	6.9164	27.9	0.6	0	0	0.04	0	0.03	0	35	18.4	248.1	105
5/29/2012	6	MS-3	233.4	2.53	236.8	6.9202	28.8	0.6	0	0	0.04	0	0.01	0	28	15.7	488.4	95.7
6/6/2012	2	MS-1	15.9	0.17	34.3	7.1002	49	0.7	0.1	0	0.03	0	0	0.02	43	19.6	TNTC	261.3
6/6/2012	2	MS-2	19.7	0.21	34.3	6.9979	40.6	0.6	0.1	0	0.03	0	0	0	16	10.2	TNTC	146.7
6/6/2012	2	MS-3	25.4	0.28	34.3	6.9681	35.9	0.6	0.1	0	0.03	0	0.01	0	9	8.48	TNTC	35.5
6/6/2012	2	MS-4	29.2	0.32	34.3	6.9642	35.5	0.6	0.1	0	0.02	0	0.01	0	6	6.97	TNTC	410.6
6/15/2012	7	MS-1	25.3	0.27	267.0	7.2709	65.2	0.8	0.2	0	0.03	0	0.03	0	7	11.3	1119.85	214.3
6/15/2012	7	MS-2	83.1	0.90	267.0	7.2207	45.3	0.7	0.2	0	0.03	0	0.03	0	16	7.36	2180	0
6/15/2012	7	MS-4	219.6	2.38	267.0	6.4227	12.51	0.3	0.1	0	0.03	0	0.02	0	5	3.63	980	0

N.S. = No Sample

Replicates and Field Blanks for OKC Field Samples

pH, EC, NO_3-N, SAR, B, Fe, Cu, Zn, Mn, TSS, Turbidity, Total Coliforms, and *E. coli*

Date	Roof	pH	EC, µS/cm	NO3N, ppm	SAR	B, ppm	Fe, ppm	Cu, ppm	Zn, ppm	Mn, ppm	TSS, mg/L	Turbidity, NTU	Total Coliforms CFU/100 mL	*E. coli* CFU/100 mL
7/10/2012	HP Field Blank	6.8403	39.9	0.2	1.2	0.1	0	0	0	0	0	0.33	0	0
7/10/2012	MS Field Blank	6.8084	38.9	0.2	1.1	0.2	0.01	0	0	0	0	0.28	0	0
7/10/2012	AS Field Blank	6.8457	41.1	0.2	1.1	0.1	0.01	0	0	0	1	0.51	0	0
4/3/2012	HP-1 REP										44			
4/3/2012	HP-1 DUP										48			
4/3/2012	HP-1 REP										50			
4/11/2012	MS-2 REP										8			
4/11/2012	AS-1 REP	7.4004	130.1	1.6	0.2	0.1	0.02	0.05	0.01	0				
4/13/2012	HP-2 REP	6.6431	20.4	0.4	0.1	0	0.02	0	0	0				
4/13/2012	MS-2 REP	7.1802	46	0.7	0.1	0	0.04	0.01	0.01	0				
4/13/2012	AS-1 REP										14			
4/19/2012	HP-3 REP	7.0196	23.4	0.3	0.1		0.03							
4/19/2012	AS-3 REP											2.19		
4/28/2012	HP-1 REP											20.8		
4/28/2012	MS-1 REP	7.6818	122.7	1.3	0.2									
4/28/2012	MS-3 REP										9	11.1		
5/11/2012	AS-1 REP											11		
5/20/2012	HP-1 REP	7.1861	41.3	0.7	0.1		0.03							
5/20/2012	HP-6 REP										5	4.71		
5/20/2012	MS-2 REP											14.8		
5/20/2012	MS-3 REP	7.1871	56.2	1	0.1		0.04	0.01	0.02					
5/29/2012	AS-2 REP												1910	0
5/29/2012	AS-5 REP	6.7868	23.3	0.5	0.1		0.03							
6/6/2012	HP-3 REP										2			
6/6/2012	HP-5 REP											3.14		
6/6/2012	MS-4 REP	7.0258	34.6	0.6	0.1		0.02							
6/6/2012	AS-1 REP												436	21.6
6/6/2012	AS-2 REP										32			
6/6/2012	AS-4 REP											3.88		
6/6/2012	AS-6 REP	6.982	43.5	1	0.1		0.02							
6/15/2012	HP-4 REP											4.71	100	0
7/9/2012	HP-5 REP												100	0
7/9/2012	AS-4 REP										33			

			HP 04/03				
			1	2	3	5	6
Class		RL, ng/L					
PAH	Naphthalene	30	98	47	0	57	55
PAH	2-Methylnaphthalene	30	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0
PAH	Phenanthrene	30	70	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0
PAH	Fluoranthene	15	148	43	15	0	15
PAH	Pyrene	10	122	44	25	19	17
PAH	Benz(a)anthracene	10	44	12	0	0	0
PAH	Chrysene	10	78	27	14	0	10
PAH	Benzo(b)fluoranthene	10	124	76	19	0	15
PAH	Benzo(k)fluoranthene	10	42	49	0	0	0
PAH	Benzo(a)pyrene	10	70	26	11	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	88	26	12	0	10
PAH	Dibenzo(a,h)anthracene	10	13	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	58	25	10	0	0
PAH	Sum PAHs	>300	955	375	106	76	122
PAH	Sum of Commonly Detected	>75	672	291	96	19	67
PAH	Sum of Probable Carcinogens	>70	459	216	56	0	35
Flame Retardant	TCEP	30	0	0	0	0	0
Flame Retardant	TDCPP	30	0	0	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0

			HP 04/11
			1
Class		RL, ng/L	
PAH	Naphthalene	30	56
PAH	2-Methylnaphthalene	30	0
PAH	Acenaphthylene	30	0
PAH	Acenaphthene	30	0
PAH	Fluorene	30	0
PAH	Phenanthrene	30	0
PAH	Anthracene	15	0
PAH	Fluoranthene	15	73
PAH	Pyrene	10	75
PAH	Benz(a)anthracene	10	19
PAH	Chrysene	10	30
PAH	Benzo(b)fluoranthene	10	36
PAH	Benzo(k)fluoranthene	10	14
PAH	Benzo(a)pyrene	10	25
PAH	Indeno(1,2,3-cd)pyrene	10	24
PAH	Dibenzo(a,h)anthracene	10	0
PAH	Benzo(g,h,i)perylene	10	21
PAH	Sum PAHs	>300	373
PAH	Sum of Commonly Detected	>75	277
PAH	Sum of Probable Carcinogens	>70	148
Flame Retardant	TCEP	30	
Flame Retardant	TDCPP	30	
Pyrethroid	Bifenthrin	10	0
Pyrethroid	Cypermethrin	90	0
Pyrethroid	Lambda-cyhalothrin	10	0

			HP 04/13		
			1	2	5
Class		RL, ng/L			
PAH	Naphthalene	30	0	0	0
PAH	2-Methylnaphthalene	30	0	0	0
PAH	Acenaphthylene	30	0	0	0
PAH	Acenaphthene	30	0	0	0
PAH	Fluorene	30	0	0	0
PAH	Phenanthrene	30	0	0	0
PAH	Anthracene	15	0	0	0
PAH	Fluoranthene	15	24	22	0
PAH	Pyrene	10	32	32	11
PAH	Benz(a)anthracene	10	0	10	0
PAH	Chrysene	10	18	11	0
PAH	Benzo(b)fluoranthene	10	24	12	0
PAH	Benzo(k)fluoranthene	10	0	0	0
PAH	Benzo(a)pyrene	10	12	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	17	12	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0
PAH	Benzo(g,h,i)perylene	10	11	11	0
PAH	Sum PAHs	>300	138	110	11
PAH	Sum of Commonly Detected	>75	127	89	11
PAH	Sum of Probable Carcinogens	>70	71	45	0
Flame Retardant	TCEP	30	0	0	33
Flame Retardant	TDCPP	30	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0

			HP 04/19		
			1	2	3
Class		RL, ng/L			
PAH	Naphthalene	30	0	0	0
PAH	2-Methylnaphthalene	30	0	0	0
PAH	Acenaphthylene	30	0	0	0
PAH	Acenaphthene	30	0	0	0
PAH	Fluorene	30	0	0	0
PAH	Phenanthrene	30	0	0	0
PAH	Anthracene	15	0	0	0
PAH	Fluoranthene	15	0	0	0
PAH	Pyrene	10	22	16	0
PAH	Benz(a)anthracene	10	0	0	0
PAH	Chrysene	10	14	10	0
PAH	Benzo(b)fluoranthene	10	23	12	0
PAH	Benzo(k)fluoranthene	10	10	0	0
PAH	Benzo(a)pyrene	10	10	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	19	10	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0
PAH	Benzo(g,h,i)perylene	10	10	0	0
PAH	Sum PAHs	>300	108	48	0
PAH	Sum of Commonly Detected	>75	98	48	0
PAH	Sum of Probable Carcinogens	>70	76	32	0
Flame Retardant	TCEP	30	0	0	37
Flame Retardant	TDCPP	30	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0

			HP 04/28		
			1	3	4
Class		RL, ng/L			
PAH	Naphthalene	30	34	42	41
PAH	2-Methylnaphthalene	30	0	0	0
PAH	Acenaphthylene	30	0	0	0
PAH	Acenaphthene	30	0	0	0
PAH	Fluorene	30	0	0	0
PAH	Phenanthrene	30	0	0	0
PAH	Anthracene	15	0	0	0
PAH	Fluoranthene	15	52	0	46
PAH	Pyrene	10	51	22	48
PAH	Benz(a)anthracene	10	21	0	12
PAH	Chrysene	10	33	13	29
PAH	Benzo(b)fluoranthene	10	59	18	55
PAH	Benzo(k)fluoranthene	10	26	0	16
PAH	Benzo(a)pyrene	10	28	0	22
PAH	Indeno(1,2,3-cd)pyrene	10	39	10	27
PAH	Dibenzo(a,h)anthracene	10	10	0	0
PAH	Benzo(g,h,i)perylene	10	35	10	25
PAH	Sum PAHs	>300	388	115	321
PAH	Sum of Commonly Detected	>75	288	63	243
PAH	Sum of Probable Carcinogens	>70	216	41	161
Flame Retardant	TCEP	30	0	33	32
Flame Retardant	TDCPP	30	0	0	30
Pyrethroid	Bifenthrin	10	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0

			HP 05/20					
			1	2	3	4	5	6
Class		RL, ng/L						
PAH	Naphthalene	30	0	0	0	0	44	0
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	85	43	0	0	0	0
PAH	Anthracene	15	0	77	0	0	0	0
PAH	Fluoranthene	15	100	48	28	20	0	0
PAH	Pyrene	10	84	30	29	19	0	0
PAH	Benz(a)anthracene	10	30	0	0	0	0	0
PAH	Chrysene	10	49	18	18	11	0	0
PAH	Benzo(b)fluoranthene	10	94	25	29	19	14	0
PAH	Benzo(k)fluoranthene	10	28	15	14	0	0	0
PAH	Benzo(a)pyrene	10	43	13	14	10	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	56	19	20	13	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	42	15	17	12	0	0
PAH	Sum PAHs	>300	611	303	169	104	58	0
PAH	Sum of Commonly Detected	>75	454	168	152	92	14	0
PAH	Sum of Probable Carcinogens	>70	300	90	95	53	14	0
Flame Retardant	TCEP	30	0	0	35	49	43	31
Flame Retardant	TDCPP	30	0	0	0	0		0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			HP 05/29
			1
Class		RL, ng/L	
PAH	Naphthalene	30	0
PAH	2-Methylnaphthalene	30	0
PAH	Acenaphthylene	30	0
PAH	Acenaphthene	30	0
PAH	Fluorene	30	0
PAH	Phenanthrene	30	32
PAH	Anthracene	15	0
PAH	Fluoranthene	15	69
PAH	Pyrene	10	66
PAH	Benz(a)anthracene	10	24
PAH	Chrysene	10	38
PAH	Benzo(b)fluoranthene	10	51
PAH	Benzo(k)fluoranthene	10	17
PAH	Benzo(a)pyrene	10	28
PAH	Indeno(1,2,3-cd)pyrene	10	35
PAH	Dibenzo(a,h)anthracene	10	0
PAH	Benzo(g,h,i)perylene	10	19
PAH	Sum PAHs	>300	379
PAH	Sum of Commonly Detected	>75	304
PAH	Sum of Probable Carcinogens	>70	193
Flame Retardant	TCEP	30	0
Flame Retardant	TDCPP	30	0
Pyrethroid	Bifenthrin	10	0
Pyrethroid	Cypermethrin	90	0
Pyrethroid	Lambda-cyhalothrin	10	15

			HP 06/06					
			1	2	3	4	5	6
Class		RL, ng/L						
PAH	Naphthalene	30	0	0	0	0	0	0
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	79	34	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	141	110	0	0	0	0
PAH	Pyrene	10	124	97	14	0	0	0
PAH	Benz(a)anthracene	10	72	42	0	0	0	0
PAH	Chrysene	10	88	39	0	0	0	0
PAH	Benzo(b)fluoranthene	10	93	42	12	0	0	0
PAH	Benzo(k)fluoranthene	10	39	24	0	0	0	0
PAH	Benzo(a)pyrene	10	61	16	0	0	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	72	31	10	0	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	46	18	0	0	0	0
PAH	Sum PAHs	>300	815	453	36	0	0	0
PAH	Sum of Commonly Detected	>75	618	359	36	0	0	0
PAH	Sum of Probable Carcinogens	>70	425	194	22	0	0	0
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	0	0	0	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			HP 06/15					
			1	2	3	4	5	6
Class		RL, ng/L						
PAH	Naphthalene	30	0	0	0	0	0	0
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	76	32	0	18	0	0
PAH	Pyrene	10	69	27	21	26	0	0
PAH	Benz(a)anthracene	10	27	0	0	10	0	0
PAH	Chrysene	10	42	16	12	14	0	0
PAH	Benzo(b)fluoranthene	10	58	30	15	17	0	0
PAH	Benzo(k)fluoranthene	10	26	11	0	0	0	0
PAH	Benzo(a)pyrene	10	31	13	0	0	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	42	18	10	10	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	25	12	0	0	0	0
PAH	Sum PAHs	>300	396	159	58	95	0	0
PAH	Sum of Commonly Detected	>75	344	147	58	85	0	0
PAH	Sum of Probable Carcinogens	>70	226	88	37	51	0	0
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	0	0	0	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			HP 07/09				
			1	2	3	4	5
Class		RL, ng/L					
PAH	Naphthalene	30	31	0	0	0	0
PAH	2-Methylnaphthalene	30	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0
PAH	Phenanthrene	30	48	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0
PAH	Fluoranthene	15	97	28	0	0	0
PAH	Pyrene	10	66	26	26	24	15
PAH	Benz(a)anthracene	10	22	0	0	0	0
PAH	Chrysene	10	41	16	12	13	0
PAH	Benzo(b)fluoranthene	10	63	38	20	19	12
PAH	Benzo(k)fluoranthene	10	40	10	0	0	0
PAH	Benzo(a)pyrene	10	29	14	0	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	48	21	16	14	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	32	19	12	12	0
PAH	Sum PAHs	>300	517	172	86	82	27
PAH	Sum of Commonly Detected	>75	384	153	74	70	27
PAH	Sum of Probable Carcinogens	>70	243	99	48	46	12
Flame Retardant	TCEP	30	75	0	48	0	0
Flame Retardant	TDCPP	30	46	40	44	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	12	0	0

OKC Metal Roof (OSU-OKC Horticulture Pavilion, HP)

Runoff Volumes and Depths for OKC Samples Analyzed for Polycyclic Aromatic Hydrocarbons, Flame Retardants, and Pyrethroid Insecticides

Date	Sample	Samples Organics	Runoff Volume (L)	Runoff Depth (mm)
4/3/2012	HP-1	1	104	1.18
4/3/2012	HP-2	2	111	1.26
4/3/2012	HP-3	3	115	1.31
4/3/2012	HP-5	5	452	5.15
4/3/2012	HP-6	6	847	9.64
4/11/2012	HP-1	1	91	1.03
4/13/2012	HP-1	1	119	1.35
4/13/2012	HP-2	2	130	1.48
4/13/2012	HP-5	5	1033	11.77
4/19/2012	HP-1	1	97	1.10
4/19/2012	HP-2	2	150	1.71
4/19/2012	HP-3	3	219	2.49
4/28/2012	HP-1	1	81	0.92
4/28/2012	HP-3	3	95	1.08
4/28/2012	HP-4	4	109	1.24
5/20/2012	HP-1	1	65	0.74
5/20/2012	HP-2	2	77	0.88
5/20/2012	HP-3	3	110	1.25
5/20/2012	HP-4	4	167	1.90
5/20/2012	HP-5	5	313	3.57
5/20/2012	HP-6	6	357	4.06
5/29/2012	HP-1	1	13	0.15
6/6/2012	HP-1	1	59	0.68
6/6/2012	HP-2	2	137	1.56
6/6/2012	HP-3	3	266	3.03
6/6/2012	HP-4	4	418	4.76
6/6/2012	HP-5	5	649	7.39
6/6/2012	HP-6	6	733	8.35
6/15/2012	HP-1	1	121	1.38
6/15/2012	HP-2	2	189	2.16
6/15/2012	HP-3	3	369	4.20
6/15/2012	HP-4	4	604	6.87
6/15/2012	HP-5	5	1687	19.22
6/15/2012	HP-6	6	2267	25.82
7/9/2012	HP-1	1	25.8	0.29
7/9/2012	HP-2	2	25.0	0.28
7/9/2012	HP-3	3	38.9	0.44
7/9/2012	HP-4	4	53.3	0.61
7/9/2012	HP-5	5	64.8	0.74

			AS 04/11
			1
Class		RL, ng/L	
PAH	Naphthalene	30	50
PAH	2-Methylnaphthalene	30	1
PAH	Acenaphthylene	30	0
PAH	Acenaphthene	30	0
PAH	Fluorene	30	0
PAH	Phenanthrene	30	40
PAH	Anthracene	15	0
PAH	Fluoranthene	15	138
PAH	Pyrene	10	121
PAH	Benz(a)anthracene	10	57
PAH	Chrysene	10	90
PAH	Benzo(b)fluoranthene	10	126
PAH	Benzo(k)fluoranthene	10	45
PAH	Benzo(a)pyrene	10	78
PAH	Indeno(1,2,3-cd)pyrene	10	91
PAH	Dibenzo(a,h)anthracene	10	26
PAH	Benzo(g,h,i)perylene	10	67
PAH	Sum PAHs	>300	930
PAH	Sum of Commonly Detected	>75	689
PAH	Sum of Probable Carcinogens	>70	513
Flame Retardant	TCEP	30	0
Flame Retardant	TDCPP	30	0
Pyrethroid	Bifenthrin	10	0
Pyrethroid	Cypermethrin	90	0
Pyrethroid	Lambda-cyhalothrin	10	0

			AS 04/13		
			1	3	4
Class		RL, ng/L			
PAH	Naphthalene	30	44	0	0
PAH	2-Methylnaphthalene	30	0	0	0
PAH	Acenaphthylene	30	0	0	0
PAH	Acenaphthene	30	0	0	0
PAH	Fluorene	30	0	0	0
PAH	Phenanthrene	30	73	0	0
PAH	Anthracene	15	0	0	0
PAH	Fluoranthene	15	255	60	34
PAH	Pyrene	10	206	65	41
PAH	Benz(a)anthracene	10	94	29	17
PAH	Chrysene	10	127	42	28
PAH	Benzo(b)fluoranthene	10	190	61	38
PAH	Benzo(k)fluoranthene	10	61	24	14
PAH	Benzo(a)pyrene	10	104	35	23
PAH	Indeno(1,2,3-cd)pyrene	10	156	48	30
PAH	Dibenzo(a,h)anthracene	10	22	0	0
PAH	Benzo(g,h,i)perylene	10	74	34	20
PAH	Sum PAHs	>300	1406	398	245
PAH	Sum of Commonly Detected	>75	1099	335	208
PAH	Sum of Probable Carcinogens	>70	754	239	150
Flame Retardant	TCEP	30	0	0	0
Flame Retardant	TDCPP	30	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0

			AS 04/19		
			1	2	3
Class		RL, ng/L			
PAH	Naphthalene	30	39	46	0
PAH	2-Methylnaphthalene	30	0	0	0
PAH	Acenaphthylene	30	0	0	0
PAH	Acenaphthene	30	0	0	0
PAH	Fluorene	30	0	0	0
PAH	Phenanthrene	30	43	77	0
PAH	Anthracene	15	0	0	0
PAH	Fluoranthene	15	51	88	38
PAH	Pyrene	10	70	80	43
PAH	Benz(a)anthracene	10	27	30	18
PAH	Chrysene	10	16	73	36
PAH	Benzo(b)fluoranthene	10	87	125	70
PAH	Benzo(k)fluoranthene	10	53	48	21
PAH	Benzo(a)pyrene	10	62	60	34
PAH	Indeno(1,2,3-cd)pyrene	10	77	101	52
PAH	Dibenzo(a,h)anthracene	10	22	13	0
PAH	Benzo(g,h,i)perylene	10	57	67	33
PAH	Sum PAHs	>300	604	808	345
PAH	Sum of Commonly Detected	>75	416	575	294
PAH	Sum of Probable Carcinogens	>70	344	450	231
Flame Retardant	TCEP	30	0	50	0
Flame Retardant	TDCPP	30	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0

			AS 05/11
			1
Class		RL, ng/L	
PAH	Naphthalene	30	147
PAH	2-Methylnaphthalene	30	62
PAH	Acenaphthylene	30	0
PAH	Acenaphthene	30	0
PAH	Fluorene	30	0
PAH	Phenanthrene	30	0
PAH	Anthracene	15	0
PAH	Fluoranthene	15	31
PAH	Pyrene	10	21
PAH	Benz(a)anthracene	10	0
PAH	Chrysene	10	0
PAH	Benzo(b)fluoranthene	10	19
PAH	Benzo(k)fluoranthene	10	10
PAH	Benzo(a)pyrene	10	12
PAH	Indeno(1,2,3-cd)pyrene	10	15
PAH	Dibenzo(a,h)anthracene	10	0
PAH	Benzo(g,h,i)perylene	10	12
PAH	Sum PAHs	>300	329
PAH	Sum of Commonly Detected	>75	108
PAH	Sum of Probable Carcinogens	>70	56
Flame Retardant	TCEP	30	59
Flame Retardant	TDCPP	30	0
Pyrethroid	Bifenthrin	10	0
Pyrethroid	Cypermethrin	90	0
Pyrethroid	Lambda-cyhalothrin	10	0

			AS 05/29				
			1	2	3	4	5
Class		RL, ng/L					
PAH	Naphthalene	30	33	0	0	0	0
PAH	2-Methylnaphthalene	30	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0
PAH	Phenanthrene	30	36	76	0	0	0
PAH	Anthracene	15	0	0	0	0	0
PAH	Fluoranthene	15	185	126	42	30	0
PAH	Pyrene	10	143	94	40	20	25
PAH	Benz(a)anthracene	10	58	42	18	0	13
PAH	Chrysene	10	114	83	30	16	17
PAH	Benzo(b)fluoranthene	10	147	95	48	18	18
PAH	Benzo(k)fluoranthene	10	47	33	13	0	0
PAH	Benzo(a)pyrene	10	82	47	21	0	11
PAH	Indeno(1,2,3-cd)pyrene	10	108	65	32	0	13
PAH	Dibenzo(a,h)anthracene	10	20	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	58	42	17	0	0
PAH	Sum PAHs	>300	1031	703	261	84	97
PAH	Sum of Commonly Detected	>75	826	543	226	84	84
PAH	Sum of Probable Carcinogens	>70	576	365	162	34	72
Flame Retardant	TCEP	30	0	0	0	0	0
Flame Retardant	TDCPP	30	0	0	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	63	75	0	0	0

			AS 06/06					
			1	2	3	4	5	6
Class		RL, ng/L						
PAH	Naphthalene	30	0	0	0	0	0	0
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	40	0	0	0	0	0
PAH	Anthracene	15	18	0	0	0	0	0
PAH	Fluoranthene	15	177	135	64	39	47	0
PAH	Pyrene	10	144	116	67	48	48	0
PAH	Benz(a)anthracene	10	116	85	40	24	22	0
PAH	Chrysene	10	121	85	45	34	26	13
PAH	Benzo(b)fluoranthene	10	164	134	66	45	36	17
PAH	Benzo(k)fluoranthene	10	46	30	29	16	13	0
PAH	Benzo(a)pyrene	10	79	58	37	23	19	0
PAH	Indeno(1,2,3-cd)pyrene	10	84	69	61	33	28	0
PAH	Dibenzo(a,h)anthracene	10	16	10	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	51	38	26	18	13	0
PAH	Sum PAHs	>300	1056	760	435	280	252	30
PAH	Sum of Commonly Detected	>75	815	627	369	238	217	30
PAH	Sum of Probable Carcinogens	>70	626	471	278	175	144	30
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	0	0	0	31	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

			AS 07/09	
			1	4
Class		RL, ng/L		
PAH	Naphthalene	30	57	0
PAH	2-Methylnaphthalene	30	0	0
PAH	Acenaphthylene	30	0	0
PAH	Acenaphthene	30	0	0
PAH	Fluorene	30	0	0
PAH	Phenanthrene	30	141	38
PAH	Anthracene	15	0	0
PAH	Fluoranthene	15	206	93
PAH	Pyrene	10	175	80
PAH	Benz(a)anthracene	10	65	27
PAH	Chrysene	10	149	63
PAH	Benzo(b)fluoranthene	10	209	86
PAH	Benzo(k)fluoranthene	10	58	24
PAH	Benzo(a)pyrene	10	91	40
PAH	Indeno(1,2,3-cd)pyrene	10	170	73
PAH	Dibenzo(a,h)anthracene	10	18	0
PAH	Benzo(g,h,i)perylene	10	109	50
PAH	Sum PAHs	>300	1448	574
PAH	Sum of Commonly Detected	>75	1058	459
PAH	Sum of Probable Carcinogens	>70	760	313
Flame Retardant	TCEP	30	126	65
Flame Retardant	TDCPP	30	0	45
Pyrethroid	Bifenthrin	10	0	0
Pyrethroid	Cypermethrin	90	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	63

OKC Asphalt Shingle Roof (AS)

Runoff Volumes and Depths for OKC Samples Analyzed for Polycyclic Aromatic Hydrocarbons, Flame Retardants, and Pyrethroid Insecticides

Date	Sample	Samples Organics	Runoff Volume (L)	Runoff Depth (mm)
4/11/2012	AS-1	1	3.68	0.40
4/13/2012	AS-1	1	4	0.39
4/13/2012	AS-3	3	15	1.58
4/13/2012	AS-4	4	22	2.38
4/19/2012	AS-1	1	4	0.39
4/19/2012	AS-2	2	17	1.78
4/19/2012	AS-3	3	26	2.76
5/11/2012	AS-1	1	3.67	0.39
5/29/2012	AS-1	1	9	0.95
5/29/2012	AS-2	2	19	2.09
5/29/2012	AS-3	3	61	6.57
5/29/2012	AS-4	4	107	11.49
5/29/2012	AS-5	5	114	12.31
6/6/2012	AS-1	1	7	0.79
6/6/2012	AS-2	2	17	1.78
6/6/2012	AS-3	3	29	3.16
6/6/2012	AS-4	4	44	4.76
6/6/2012	AS-5	5	52	5.58
6/6/2012	AS-6	6	63	6.82
7/9/2012	AS-1	1	12.87	1.38
7/9/2012	AS-4	4	18.39	1.98

			MS 04/11	
			1	2
Class		RL, ng/L		
PAH	Naphthalene	30	0	0
PAH	2-Methylnaphthalene	30	0	0
PAH	Acenaphthylene	30	0	0
PAH	Acenaphthene	30	0	0
PAH	Fluorene	30	0	0
PAH	Phenanthrene	30	0	0
PAH	Anthracene	15	0	0
PAH	Fluoranthene	15	0	0
PAH	Pyrene	10	10	19
PAH	Benz(a)anthracene	10	0	0
PAH	Chrysene	10	0	13
PAH	Benzo(b)fluoranthene	10	0	20
PAH	Benzo(k)fluoranthene	10	0	0
PAH	Benzo(a)pyrene	10	0	11
PAH	Indeno(1,2,3-cd)pyrene	10	0	16
PAH	Dibenzo(a,h)anthracene	10	0	0
PAH	Benzo(g,h,i)perylene	10	0	14
PAH	Sum PAHs	>300	10	93
PAH	Sum of Commonly Detected	>75	10	79
PAH	Sum of Probable Carcinogens	>70	0	60
Flame Retardant	TCEP	30	0	34
Flame Retardant	TDCPP	30	44	0
Pyrethroid	Bifenthrin	10	0	0
Pyrethroid	Cypermethrin	90	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0

			MS 04/13		
			1	2	3
Class		RL, ng/L			
PAH	Naphthalene	30	0	0	0
PAH	2-Methylnaphthalene	30	0	0	0
PAH	Acenaphthylene	30	0	0	0
PAH	Acenaphthene	30	0	0	0
PAH	Fluorene	30	0	0	0
PAH	Phenanthrene	30	0	0	0
PAH	Anthracene	15	0	0	0
PAH	Fluoranthene	15	0	0	0
PAH	Pyrene	10	18	13	0
PAH	Benz(a)anthracene	10	0	0	0
PAH	Chrysene	10	13	0	0
PAH	Benzo(b)fluoranthene	10	17	12	0
PAH	Benzo(k)fluoranthene	10	0	0	0
PAH	Benzo(a)pyrene	10	10	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	12	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0
PAH	Benzo(g,h,i)perylene	10	11	0	0
PAH	Sum PAHs	>300	81	25	0
PAH	Sum of Commonly Detected	>75	70	25	0
PAH	Sum of Probable Carcinogens	>70	52	12	0
Flame Retardant	TCEP	30	0	0	0
Flame Retardant	TDCPP	30	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0

			MS 04/19
			2
Class		RL, ng/L	
PAH	Naphthalene	30	0
PAH	2-Methylnaphthalene	30	0
PAH	Acenaphthylene	30	0
PAH	Acenaphthene	30	0
PAH	Fluorene	30	0
PAH	Phenanthrene	30	0
PAH	Anthracene	15	0
PAH	Fluoranthene	15	0
PAH	Pyrene	10	0
PAH	Benz(a)anthracene	10	0
PAH	Chrysene	10	0
PAH	Benzo(b)fluoranthene	10	10
PAH	Benzo(k)fluoranthene	10	0
PAH	Benzo(a)pyrene	10	0
PAH	Indeno(1,2,3-cd)pyrene	10	0
PAH	Dibenzo(a,h)anthracene	10	0
PAH	Benzo(g,h,i)perylene	10	0
PAH	Sum PAHs	>300	10
PAH	Sum of Commonly Detected	>75	10
PAH	Sum of Probable Carcinogens	>70	10
Flame Retardant	TCEP	30	0
Flame Retardant	TDCPP	30	0
Pyrethroid	Bifenthrin	10	0
Pyrethroid	Cypermethrin	90	0
Pyrethroid	Lambda-cyhalothrin	10	0

			MS 04/28		
			1	3	4
Class		RL, ng/L			
PAH	Naphthalene	30	59	0	0
PAH	2-Methylnaphthalene	30	0	0	0
PAH	Acenaphthylene	30	0	0	0
PAH	Acenaphthene	30	0	0	0
PAH	Fluorene	30	0	0	0
PAH	Phenanthrene	30	0	0	0
PAH	Anthracene	15	0	0	0
PAH	Fluoranthene	15	29	0	0
PAH	Pyrene	10	35	0	0
PAH	Benz(a)anthracene	10	10	0	0
PAH	Chrysene	10	19	0	0
PAH	Benzo(b)fluoranthene	10	33	10	10
PAH	Benzo(k)fluoranthene	10	12	0	0
PAH	Benzo(a)pyrene	10	18	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	22	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0
PAH	Benzo(g,h,i)perylene	10	19	0	0
PAH	Sum PAHs	>300	256	10	10
PAH	Sum of Commonly Detected	>75	168	10	10
PAH	Sum of Probable Carcinogens	>70	114	10	10
Flame Retardant	TCEP	30	30	40	42
Flame Retardant	TDCPP	30	48	57	41
Pyrethroid	Bifenthrin	10	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0

			MS 05/20		
			1	2	3
Class		RL, ng/L			
PAH	Naphthalene	30	0	0	0
PAH	2-Methylnaphthalene	30	0	0	0
PAH	Acenaphthylene	30	0	0	0
PAH	Acenaphthene	30	0	0	0
PAH	Fluorene	30	0	0	0
PAH	Phenanthrene	30	0	0	0
PAH	Anthracene	15	0	0	0
PAH	Fluoranthene	15	17	0	0
PAH	Pyrene	10	21	16	0
PAH	Benz(a)anthracene	10	0	0	0
PAH	Chrysene	10	11	0	0
PAH	Benzo(b)fluoranthene	10	24	18	0
PAH	Benzo(k)fluoranthene	10	10	0	0
PAH	Benzo(a)pyrene	10	0	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	12	11	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0
PAH	Benzo(g,h,i)perylene	10	0	0	0
PAH	Sum PAHs	>300	95	45	0
PAH	Sum of Commonly Detected	>75	95	45	0
PAH	Sum of Probable Carcinogens	>70	57	29	0
Flame Retardant	TCEP	30	0	33	0
Flame Retardant	TDCPP	30	40	36	0
Pyrethroid	Bifenthrin	10	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0

			MS 05/29		
			1	2	3
Class		RL, ng/L			
PAH	Naphthalene	30	37	0	0
PAH	2-Methylnaphthalene	30	0	0	0
PAH	Acenaphthylene	30	0	0	0
PAH	Acenaphthene	30	0	0	0
PAH	Fluorene	30	0	0	0
PAH	Phenanthrene	30	50	0	0
PAH	Anthracene	15	0	0	0
PAH	Fluoranthene	15	113	58	0
PAH	Pyrene	10	104	61	23
PAH	Benz(a)anthracene	10	39	22	10
PAH	Chrysene	10	77	38	15
PAH	Benzo(b)fluoranthene	10	122	65	25
PAH	Benzo(k)fluoranthene	10	47	33	0
PAH	Benzo(a)pyrene	10	54	34	11
PAH	Indeno(1,2,3-cd)pyrene	10	81	48	17
PAH	Dibenzo(a,h)anthracene	10	0	0	0
PAH	Benzo(g,h,i)perylene	10	46	28	11
PAH	Sum PAHs	>300	770	387	112
PAH	Sum of Commonly Detected	>75	598	337	91
PAH	Sum of Probable Carcinogens	>70	420	240	78
Flame Retardant	TCEP	30	0	0	0
Flame Retardant	TDCPP	30	45	31	0
Pyrethroid	Bifenthrin	10	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	117	0	0

			MS 06/06			
			1	2	3	4
Class		RL, ng/L				
PAH	Naphthalene	30	0	0	0	0
PAH	2-Methylnaphthalene	30	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0
PAH	Fluorene	30	0	0	0	0
PAH	Phenanthrene	30	0	0	0	0
PAH	Anthracene	15	0	0	0	0
PAH	Fluoranthene	15	49	19	0	0
PAH	Pyrene	10	57	25	11	10
PAH	Benz(a)anthracene	10	29	11	0	0
PAH	Chrysene	10	45	15	0	0
PAH	Benzo(b)fluoranthene	10	56	26	10	11
PAH	Benzo(k)fluoranthene	10	23	14	0	0
PAH	Benzo(a)pyrene	10	30	12	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	43	18	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	24	12	0	0
PAH	Sum PAHs	>300	356	152	21	21
PAH	Sum of Commonly Detected	>75	303	129	21	21
PAH	Sum of Probable Carcinogens	>70	226	96	10	11
Flame Retardant	TCEP	30	0	0	0	0
Flame Retardant	TDCPP	30	41	31	0	31
Pyrethroid	Bifenthrin	10	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0

			MS 06/15		
			1	2	4
Class		RL, ng/L			
PAH	Naphthalene	30	0	0	0
PAH	2-Methylnaphthalene	30	0	0	0
PAH	Acenaphthylene	30	0	0	0
PAH	Acenaphthene	30	0	0	0
PAH	Fluorene	30	0	0	0
PAH	Phenanthrene	30	0	0	0
PAH	Anthracene	15	0	0	0
PAH	Fluoranthene	15	22	0	0
PAH	Pyrene	10	28	15	0
PAH	Benz(a)anthracene	10	13	0	0
PAH	Chrysene	10	23	13	0
PAH	Benzo(b)fluoranthene	10	28	14	0
PAH	Benzo(k)fluoranthene	10	10	0	0
PAH	Benzo(a)pyrene	10	13	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	17	12	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0
PAH	Benzo(g,h,i)perylene	10	14	10	0
PAH	Sum PAHs	>300	168	64	0
PAH	Sum of Commonly Detected	>75	141	54	0
PAH	Sum of Probable Carcinogens	>70	104	39	0
Flame Retardant	TCEP	30	0	0	0
Flame Retardant	TDCPP	30	37	30	0
Pyrethroid	Bifenthrin	10	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0

OKC Tar and Gravel Roof (OSU-OKC Maintenance Shop, MS)

Runoff Volumes and Depths for OKC Samples Analyzed for Polycyclic Aromatic Hydrocarbons, Flame Retardants, and Pyrethroid Insecticides

Date	Sample	Samples Organics	Runoff Volume (L)	Runoff Depth (mm)
4/11/2012	MS-1	1	32	0.35
4/11/2012	MS-2	2	39	0.43
4/13/2012	MS-1	1	63	0.68
4/13/2012	MS-2	2	84	0.91
4/13/2012	MS-3	3	123	1.33
4/19/2012	MS-2	2	94	1.02
4/28/2012	MS-1	1	3	0.03
4/28/2012	MS-3	3	41	0.45
4/28/2012	MS-4	4	69	0.75
5/20/2012	MS-1	1	4	0.05
5/20/2012	MS-2	2	31	0.33
5/20/2012	MS-3	3	95	1.03
5/29/2012	MS-1	1	31	0.34
5/29/2012	MS-2	2	202	2.19
5/29/2012	MS-3	3	231	2.50
6/6/2012	MS-1	1	14	0.15
6/6/2012	MS-2	2	19	0.20
6/6/2012	MS-3	3	23	0.25
6/6/2012	MS-4	4	28	0.30
6/15/2012	MS-1	1	21	0.23
6/15/2012	MS-2	2	52	0.57
6/15/2012	MS-4	4	205	2.23

Polycyclic Aromatic Hydrocarbons, Flame Retardants, and Pyrethroid Insecticide Results from OKC Lab and Field Blanks

Class		RL, ng/L	Lab Blank 05/21	Lab Blank 06/08	Lab Blank 07/10	HP Field Blank	MS Field Blank	AS Field Blank
PAH	Naphthalene	30	0	0	33	0	0	0
PAH	2-Methylnaphthalene	30	0	0	0	0	0	0
PAH	Acenaphthylene	30	0	0	0	0	0	0
PAH	Acenaphthene	30	0	0	0	0	0	0
PAH	Fluorene	30	0	0	0	0	0	0
PAH	Phenanthrene	30	0	0	0	0	0	0
PAH	Anthracene	15	0	0	0	0	0	0
PAH	Fluoranthene	15	0	0	0	0	0	0
PAH	Pyrene	10	0	0	0	0	0	0
PAH	Benz(a)anthracene	10	0	0	0	0	0	0
PAH	Chrysene	10	0	0	0	0	0	0
PAH	Benzo(b)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(k)fluoranthene	10	0	0	0	0	0	0
PAH	Benzo(a)pyrene	10	0	0	0	0	0	0
PAH	Indeno(1,2,3-cd)pyrene	10	0	0	0	0	0	0
PAH	Dibenzo(a,h)anthracene	10	0	0	0	0	0	0
PAH	Benzo(g,h,i)perylene	10	0	0	0	0	0	0
Flame Retardant	TCEP	30	0	0	0	0	0	0
Flame Retardant	TDCPP	30	0	0	0	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0
Pyrethroid	Lambda-cyhalothrin	10	0	0	0	0	0	0

Surrogate Recoveries from Organics Testing of Rainfall Simulation Samples

Includes results from samples that were excluded from the study due to incorrect field sampling.

Average recovery 89.7% ± 19%

		Surrogate		
		pterphenyl	Amount Expected	Percent recovered
HP 04/03	1	514	500	102.8
	2	526	500	105.2
	3	309	500	61.8
	4	325	500	65
	5	406	500	81.2
	6	427	500	85.4
HP 04/11	1	28	25	112
	2	23	25	92
	3	25	25	100
	4	26	25	104
	5	35	25	140
	6	26	50	52
AS 04/11	1	53	50	106
	2	40	50	80
	3	35	50	70
	4	34	50	68
	5	35	50	70
	6	38	50	76
MS 04/11	1	29	50	58
	2	38	50	76
	3	38	50	76
	4	41	50	82
	5	40	50	80
	6	32	50	64
HP 04/13	1	25	25	100
	2	28	25	112
	3	29	25	116
	4	32	25	128
	5	27	25	108
	6	30	25	120
AS 04/13	1	25	25	100
	2	34	25	136
	3	31	25	124
	4	28	25	112
	5	28	25	112
	6	28	25	112
MS 04/13	1	27	25	108
	2	26	25	104
	3	29	25	116
	4	27	25	108
	5	18	25	72

	6	23	25	92
HP 04/19	1	28	25	112
	2	32	25	128
	3	30	25	120
	4	26	25	104
	5	28	25	112
	6	30	25	120
AS 04/19	1	29	25	116
	2	32	25	128
	3	28	25	112
	4	25	25	100
	5	26	25	104
	6	26	25	104
MS 04/19	1	25	25	100
	2	24	25	96
	3	24	25	96
	4	27	25	108
	5	22	25	88
	6	25	25	100
HP 04/28	1	30	25	120
	2	22	25	88
	3	32	25	128
	4	31	25	124
	5	29	25	116
	6	25	25	100
MS 04/28	1	30	25	120
	2	32	25	128
	3	32	25	128
	4	26	25	104
	5	22	25	88
	6	21	25	84
AS 05/11	1	35	50	70
	2	35	50	70
	3	37	50	74
	4	34	50	68
	5	39	50	78
	6	37	50	74
MS 05/11	1	38	50	76
	2	35	50	70
	3	36	50	72
	4	38	50	76
	5	37	50	74
	6	41	50	82
HP 05/20	1	28	25	112
	2	24	25	96
	3	22	25	88
	4	18	25	72
	5	24	25	96
	6	20	25	80

MS 05/20	1	19	25	76
	2	23	25	92
	3	24	25	96
	4	16	25	64
	5	25	25	100
	6	28	25	112
HP 05/29	1	18	25	72
	2	20	25	80
	3	14	25	56
	4	18	25	72
	5	14	25	56
	6	23	25	92
AS 05/29	1	17	25	68
	2	24	25	96
	3	20	25	80
	4	21	25	84
	5	22	25	88
	6	21	25	84
MS 05/29	1	20	25	80
	2	21	25	84
	3	17	25	68
	4	17	25	68
	5	18	25	72
	6	14	25	56
HP 06/06	1	23	25	92
	2	21	25	84
	3	23	25	92
	4	24	25	96
	5	24	25	96
	6	17	25	68
AS 06/06	1	24	25	96
	2	16	25	64
	3	16	25	64
	4	20	25	80
	5	24	25	96
	6	15	25	60
MS 06/06	1	18	25	72
	2	20	25	80
	3	17	25	68
	4	24	25	96
	5	25	25	100
	6	22	25	88
HP 06/15	1	20	25	80
	2	18	25	72
	3	20	25	80
	4	24	25	96
	5	17	25	68
	6	19	25	76
	1	23	25	92

MS 06/15	2	20	25	80
	3	31	25	124
	4	18	25	72
	5	19	25	76
	6	20	25	80
HP 07/09	1	19	25	76
	2	15	25	60
	3	23	25	92
	4	19	25	76
	5	26	25	104
	6	22	25	88
AS 07/09	1	23	25	92
	2	21	25	84
	3	18	25	72
	4	21	25	84
	5	16	25	64
	6	21	25	84
MS 07/09	1	20	25	80
	2	18	25	72
	3	20	25	80
	4	24	25	96
	5	18	25	72
	6	18	25	72

APPENDIX C

PAH ACCUMULATION IN SOILS PILOT STUDY DATA

Solution Concentrations (ng/mL)

Class		RL, ng/ml	Horticulture Pavilion OKC -DS	Horticulture Pavilion OKC-A	Physical Plant Admin. Bldg - DS	Physical Plant Admin. Bldg - A	Allen Suites - DS	Allen Suites - A	BAE Bioenergy Lab - DS	BAE Bioenergy Lab - A	Construction Technology Lab - DS	Construction Technology Lab - A	Kubat House - DS	Kubat House - A	Career Tech - DS	Career Tech - A
PAH	Naphthalene	40	43	71	50	90	153	0	108	0	70	0	0	0	0	0
PAH	2-methyl naphthalene	40	25	0	0	0	75	0	0	0	0	0	0	0	0	0
PAH	Acenaphthylene	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PAH	Acenaphthene	40	73	0	30	0	0	0	77	0	68	0	0	0	81	53
PAH	Fluorene	40	65	0	0	0	0	0	60	0	60	0	0	0	63	0
PAH	Phenanthrene	40	953	180	75	229	0	0	439	47	596	117	149	0	480	182
PAH	Anthracene	15	83	31	22	33	0	0	35	0	68	33	30	0	29	20
PAH	Fluoranthene	15	1878	399	169	791	26	110	50	0	465	202	350	0	509	131
PAH	Pyrene	10	1323	283	135	551	21	77	23	0	354	186	273	32	341	88
PAH	benz(a)anthracene	10	568	102	78	230	0	35	0	0	169	129	136	13	153	43
PAH	chrysene	10	923	194	110	360	14	51	11	0	253	133	219	25	228	62
PAH	benzo(b)fluoranthene	10	1287	240	120	418	15	57	13	0	283	220	245	37	279	136
PAH	benzo(k)fluoranthene	10	416	101	57	177	0	19	0	0	102	69	98	13	86	76
PAH	Benzo(a)pyrene	10	691	145	87	219	0	38	0	0	192	140	154	18	166	46
PAH	Indeno(1,2,3-cd)pyrene	10	1273	271	85	349	10	48	11	0	289	199	192	26	243	57
PAH	dibenzo(a,h)anthracene	10	146	21	11	32	0	0	0	0	27	11	17	0	18	0
PAH	benzo(g,h,i)perylene	10	713	141	47	161	0	29	0	0	155	100	136	18	138	30
PAH	Sum PAHs	--	10460	2179	1076	3640	314	464	827	47	3151	1539	1999	182	2814	924
PAH	Sum of Commonly Detected	>70	7791	1633	763	2865	86	400	108	0	1938	1149	1531	151	1852	596
Flame Retardant	TCEP	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Flame Retardant	TDCPP	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrethroid	Bifenthrin	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrethroid	Cypermethrin	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrethroid	lambda cyhalothrin	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Solution Concentrations Continued (ng/mL)

	Bleden - DS	Belden - A	Jones Village - DS	Jones Village - A	Thatcher - DS	Thatcher - A	Storm House - DS	Storm Barn - A	Public Information Building - DS	Public Information Building - A	Fire Protection Safety Lab - A	BAE Lab - DS	BAE Lab - A	Physical Plant North - DS	Physical Plant North - A	HSEC OKC - DS	HSEC OKC - A	Agriculture Resource Center OKC - DS	Agriculture Resource Center OKC - A	Storm Barn - DS	Fire Protection Lab - DS
Naphthalene	0	56	80	137	347	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methyl naphthalene	0	0	51	58	238	0	46	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acenaphthylene	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acenaphthene	48	42	212	575	1358	43	45	0	80	49	108	60	65	50	0	40	46	57	0	53	127
Fluorene	0	0	158	414	1075	0	0	0	59	0	77	144	0	0	0	0	0	0	0	0	94
Phenanthrene	176	45	1481	4170	8318	264	107	0	290	120	450	197	220	0	0	120	42	96	0	146	1062
Anthracene	20	0	221	703	2252	29	0	0	79	53	156	35	58	0	0	21	16	0	0	30	190
Fluoranthene	349	42	1769	5395	8898	47	49	0	484	422	1455	187	351	332	140	546	206	281	71	31	2375
Pyrene	252	18	1230	3720	7802	25	34	21	355	317	1380	185	253	252	122	396	176	217	64	17	2176
benz(a)anthracene	104	0	720	2670	7752	11	13	0	171	170	722	81	135	120	67	188	98	108	33	0	1060
chrysene	214	15	705	2032	5319	11	37	0	180	187	642	103	157	189	92	294	140	183	61	11	1132
benzo(b)fluoranthene	313	20	879	3470	9163	10	46	0	218	266	885	176	219	303	138	415	213	348	93	11	1821
benzo(k)fluoranthene	111	0	297	1149	2771	0	18	0	99	103	311	61	85	99	58	154	102	111	43	4	502
Benzo(a)pyrene	179	10	545	1864	6123	0	20	0	155	175	647	105	142	167	94	214	130	161	49	0	1071
Indeno(1,2,3-cd)pyrene	288	13	776	2219	8434	11	19	0	204	198	851	123	166	158	121	349	171	232	75	0	1420
dibenzo(a,h)anthracene	23	0	87	218	570	0	0	0	15	12	121	11	12	26	0	19	15	16	0	0	122
benzo(g,h,i)perylene	150	0	394	958	4705	0	23	0	103	102	447	76	95	133	78	175	93	143	49	0	823
Sum PAHs	2227	261	9605	29752	75125	451	457	21	2492	2174	8252	1544	1958	1829	910	2931	1448	1953	538	303	13975
Sum of Commonly Detected	1706	118	6201	19849	48510	104	223	21	1695	1668	6171	940	1373	1500	765	2368	1138	1533	456	74	10497
TCEP	0	0	0	0	0	0	0	0	85	0	0	0	0	0	0	0	0	0	0	0	0
TDCPP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bifenthrin	230	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cypermethrin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
lambda cyhalothrin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Soil Concentrations (ng/g) (1.5 g soil)

Class		RL, ng/g	Horticulture Pavilion OKC -DS	Horticulture Pavilion OKC-A	Physical Plant Admin. Bldg - DS	Physical Plant Admin. Bldg - A	Allen Suites - DS	Allen Suites - A	BAE Bioenergy Lab - DS	BAE Bioenergy Lab - A	Construction Technology Lab - DS	Construction Technology Lab - A	Kubat House - DS	Kubat House - A	Career Tech - DS	Career Tech - A
PAH	Napthalene	13.3	14.3	23.7	16.7	30.0	51.0	0.0	36.0	0.0	23.3	0.0	0.0	0.0	0.0	0.0
PAH	2-methyl napthalene	13.3	8.3	0.0	0.0	0.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PAH	Acenapthylene	13.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PAH	Acenapthene	13.3	24.3	0.0	10.0	0.0	0.0	0.0	25.7	0.0	22.7	0.0	0.0	0.0	27.0	17.7
PAH	Fluorene	13.3	21.7	0.0	0.0	0.0	0.0	0.0	20.0	0.0	20.0	0.0	0.0	0.0	21.0	0.0
PAH	Phenanthrene	13.3	317.7	60.0	25.0	76.3	0.0	0.0	146.3	15.7	198.7	39.0	49.7	0.0	160.0	60.7
PAH	Anthracene	5.0	27.7	10.3	7.3	11.0	0.0	0.0	11.7	0.0	22.7	11.0	10.0	0.0	9.7	6.7
PAH	Fluoranthene	5.0	626.0	133.0	56.3	263.7	8.7	36.7	16.7	0.0	155.0	67.3	116.7	0.0	169.7	43.7
PAH	Pyrene	3.3	441.0	94.3	45.0	183.7	7.0	25.7	7.7	0.0	118.0	62.0	91.0	10.7	113.7	29.3
PAH	benzo(a)anthracene	3.3	189.3	34.0	26.0	76.7	0.0	11.7	0.0	0.0	56.3	43.0	45.3	4.3	51.0	14.3
PAH	chrysene	3.3	307.7	64.7	36.7	120.0	4.7	17.0	3.7	0.0	84.3	44.3	73.0	8.3	76.0	20.7
PAH	benzo(b)fluoranthene	3.3	429.0	80.0	40.0	139.3	5.0	19.0	4.3	0.0	94.3	73.3	81.7	12.3	93.0	45.3
PAH	benzo(k)fluoranthene	3.3	138.7	33.7	19.0	59.0	0.0	6.3	0.0	0.0	34.0	23.0	32.7	4.3	28.7	25.3
PAH	Benzo(a)pyrene	3.3	230.3	48.3	29.0	73.0	0.0	12.7	0.0	0.0	64.0	46.7	51.3	6.0	55.3	15.3
PAH	Indeno(1,2,3-cd)pyrene	3.3	424.3	90.3	28.3	116.3	3.3	16.0	3.7	0.0	96.3	66.3	64.0	8.7	81.0	19.0
PAH	dibenzo(a,h)anthracene	3.3	48.7	7.0	3.7	10.7	0.0	0.0	0.0	0.0	9.0	3.7	5.7	0.0	6.0	0.0
PAH	benzo(g,h,i)perylene	3.3	237.7	47.0	15.7	53.7	0.0	9.7	0.0	0.0	51.7	33.3	45.3	6.0	46.0	10.0
PAH	Sum PAHs	120	3487	726	359	1213	105	155	276	16	1050	513	666	61	938	308
PAH	Sum of Commonly Detected	25	2597	544	254	955	29	133	36	0	646	383	510	50	617	199
PAH	Carcinogens	23	1768	358	183	595	13	83	12	0	438	300	354	44	391	140
Flame Retardant	TCEP	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Flame Retardant	TDCPP	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrethroid	Bifenthrin	3.33	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrethroid	Cypermethrin	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrethroid	lambda cyhalothrin	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Soil Concentrations Continued (ng/g) (1.5 g soil)

	Belden - DS	Belden - A	Jones Vilage - DS	Jones Village - A	Thatcher - DS	Thatcher - A	Storm House - DS	Storm Barn - A	Public Information Building - DS	Public Information Building - A	Fire Protection Safety Lab - A	BAE Lab - DS	BAE Lab - A	Physical Plant North - DS	Physical Plant North - A	HSEC OKC - DS	HSEC OKC - A	Agriculture Resource Center OKC - DS	Agriculture Resource Center OKC - A	Storm Barn - DS	Fire Protection Lab - DS
Naphthalene	0.0	18.7	26.7	45.7	115.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2-methyl naphthalene	0.0	0.0	17.0	19.3	79.3	0.0	15.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Acenaphthylene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Acenaphthene	16.0	14.0	70.7	191.7	452.7	14.3	15.0	0.0	26.7	16.3	36.0	20.0	21.7	16.7	0.0	13.3	15.3	19.0	0.0	17.7	42.3
Fluorene	0.0	0.0	52.7	138.0	358.3	0.0	0.0	0.0	19.7	0.0	25.7	48.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	31.3
Phenanthrene	58.7	15.0	493.7	1390.0	2772.7	88.0	35.7	0.0	96.7	40.0	150.0	65.7	73.3	0.0	0.0	40.0	14.0	32.0	0.0	48.7	354.0
Anthracene	6.7	0.0	73.7	234.3	750.7	9.7	0.0	0.0	26.3	17.7	52.0	11.7	19.3	0.0	0.0	7.0	5.3	0.0	0.0	10.0	63.3
Fluoranthene	116.3	14.0	589.7	1798.3	2966.0	15.7	16.3	0.0	161.3	140.7	485.0	62.3	117.0	110.7	46.7	182.0	68.7	93.7	23.7	10.3	791.7
Pyrene	84.0	6.0	410.0	1240.0	2600.7	8.3	11.3	7.0	118.3	105.7	460.0	61.7	84.3	84.0	40.7	132.0	58.7	72.3	21.3	5.7	725.3
benz(a)anthracene	34.7	0.0	240.0	890.0	2584.0	3.7	4.3	0.0	57.0	56.7	240.7	27.0	45.0	40.0	22.3	62.7	32.7	36.0	11.0	0.0	353.3
chrysene	71.3	5.0	235.0	677.3	1773.0	3.7	12.3	0.0	60.0	62.3	214.0	34.3	52.3	63.0	30.7	98.0	46.7	61.0	20.3	3.7	377.3
benzo(b)fluoranthene	104.3	6.7	293.0	1156.7	3054.3	3.3	15.3	0.0	72.7	88.7	295.0	58.7	73.0	101.0	46.0	138.3	71.0	116.0	31.0	3.7	607.0
benzo(k)fluoranthene	37.0	0.0	99.0	383.0	923.7	0.0	6.0	0.0	33.0	34.3	103.7	20.3	28.3	33.0	19.3	51.3	34.0	37.0	14.3	1.3	167.3
Benzo(a)pyrene	59.7	3.3	181.7	621.3	2041.0	0.0	6.7	0.0	51.7	58.3	215.7	35.0	47.3	55.7	31.3	71.3	43.3	53.7	16.3	0.0	357.0
Indeno(1,2,3-cd)pyrene	96.0	4.3	258.7	739.7	2811.3	3.7	6.3	0.0	68.0	66.0	283.7	41.0	55.3	52.7	40.3	116.3	57.0	77.3	25.0	0.0	473.3
dibenzo(a,h)anthracene	7.7	0.0	29.0	72.7	190.0	0.0	0.0	0.0	5.0	4.0	40.3	3.7	4.0	8.7	0.0	6.3	5.0	5.3	0.0	0.0	40.7
benzo(g,h,i)perylene	50.0	0.0	131.3	319.3	1568.3	0.0	7.7	0.0	34.3	34.0	149.0	25.3	31.7	44.3	26.0	58.3	31.0	47.7	16.3	0.0	274.3
Sum PAHs	742	87	3202	9917	25042	150	152	7	831	725	2751	515	653	610	303	977	483	651	179	101	4658
Sum of Commonly Detected	569	39	2067	6616	16170	35	74	7	565	556	2057	313	458	500	255	789	379	511	152	25	3499
TCEP	411	19	1336	4541	13377	14	51	0	347	370	1393	220	305	354	190	544	290	386	118	9	2376
TDCPP	0	0	0	0	0	0	0	0	21.25	0	0	0	0	0	0	0	0	0	0	0	0
Bifenthrin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cypermethrin	57.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
lambda cyhalothrin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Soil Study Replicates Results

	Solution Concentrations (ng/mL)			Soil Concentrations (ng/g)		
	Allen - DS Replicate	Physical Plant Administration - DS Replicate	Horticulture Pavilion OKC - DS Replicate	Allen - DS Replicate	Physical Plant Administration - DS Replicate	Horticulture Pavilion OKC - DS Replicate
Naphthalene	0	0	0	0.0	0.0	0.0
2-methyl naphthalene	0	0	0	0.0	0.0	0.0
Acenaphthylene	0	0	0	0.0	0.0	0.0
Acenaphthene	0	50	62	0.0	16.7	20.7
Fluorene	0	0	49	0.0	0.0	16.3
Phenanthrene	0	146	605	0.0	48.7	201.7
Anthracene	0	0	48	0.0	0.0	16.0
Fluoranthene	35	275	1336	11.7	91.7	445.3
Pyrene	35	205	959	11.7	68.3	319.7
benz(a)anthracene	0	130	464	0.0	43.3	154.7
chrysene	27	175	726	9.0	58.3	242.0
benzo(b)fluoranthene	31	213	1223	10.3	71.0	407.7
benzo(k)fluoranthene	0	111	383	0.0	37.0	127.7
Benzo(a)pyrene	0	117	641	0.0	39.0	213.7
Indeno(1,2,3-cd)pyrene	15	129	1010	5.0	43.0	336.7
dibenzo(a,h)anthracene	0	17	88	0.0	5.7	29.3
benzo(g,h,i)perylene	12	70	612	4.0	23.3	204.0
Sum PAHs	155	1638	8206	52	546	2735
Sum of Commonly Detected	143	1225	6278	48	408	2093
TCEP	0	0	0	24	297	1512
TDCPP	0	0	0	0	0	0
Bifenthrin	0	0	0	0	0	0
Cypermethrin	0	0	0	0	0	0
lambda cyhalothrin	0	0	0	0	0	0

Soil QA/QC: Recovery of Surrogate From Soils (Practice)

Class		RL, ng/ml	Clean 6	s1	s2	s3	s4	s5
PAH	Naphthalene	30	165	247	267	239	204	219
PAH	2-methyl naphthalene	30	90	180	175	178	162	162
PAH	Acenaphthylene	30	10	122	122	117	106	105
PAH	Acenaphthene	30	70	186	193	186	173	171
PAH	Fluorene	30	70	188	201	191	183	179
PAH	Phenanthrene	30	355	450	465	401	482	429
PAH	Anthracene	15	14	125	126	125	121	119
PAH	Fluoranthene	15	60	190	170	163	167	166
PAH	Pyrene	10	15	135	132	132	128	123
PAH	benz(a)anthracene	10	4	111	107	111	103	91
PAH	chrysene	10	4	112	116	124	107	112
PAH	benzo(b)fluoranthene	10	0	69	80	79	66	64
PAH	benzo(k)fluoranthene	10	0	83	86	89	79	84
PAH	Benzo(a)pyrene	10	0	70	76	78	79	74
PAH	Indeno(1,2,3-cd)pyrene	10	0	84	93	93	79	76
PAH	dibenzo(a,h)anthracene	10	0	99	93	101	80	86
PAH	benzo(g,h,i)perylene	10	0	76	85	89	81	74
Surrogate	p terph		152	149	146	144	141	157

Soil QA/QC Lab Spike Results

Class		spiked	Clean 6	c1	c2	c3	c4	c5	avg	sd	Avg (%)	Sd (%)
PAH	Naphthalene	100	0	82	102	74	39	54	70.2	24.49898	70.2	24.49898
PAH	2-methyl naphthalene	100	0	90	85	88	72	72	81.4	8.763561	81.4	8.763561
PAH	Acenaphthylene	100	0	112	112	107	96	95	104.4	8.38451	104.4	8.38451
PAH	Acenaphthene	100	0	116	123	116	103	101	111.8	9.418068	111.8	9.418068
PAH	Fluorene	100	0	118	131	121	113	109	118.4	8.414274	118.4	8.414274
PAH	Phenanthrene	100	0	95	110	46	127	74	90.4	31.56422	90.4	31.56422
PAH	Anthracene	100	0	111	112	111	107	105	109.2	3.03315	109.2	3.03315
PAH	Fluoranthene	100	0	130	110	103	107	106	111.2	10.80278	111.2	10.80278
PAH	Pyrene	100	0	120	117	117	113	108	115	4.636809	115	4.636809
PAH	benz(a)anthracene	100	0	107	103	107	99	87	100.6	8.294577	100.6	8.294577
PAH	chrysene	100	0	108	112	120	103	108	110.2	6.340347	110.2	6.340347
PAH	benzo(b)fluoranthene	100	0	69	80	79	66	64	71.6	7.436397	71.6	7.436397
PAH	benzo(k)fluoranthene	100	0	83	86	89	79	84	84.2	3.701351	84.2	3.701351
PAH	Benzo(a)pyrene	100	0	70	76	78	79	74	75.4	3.577709	75.4	3.577709
PAH	Indeno(1,2,3-cd)pyrene	100	0	84	93	93	79	76	85	7.842194	85	7.842194
PAH	dibenzo(a,h)anthracene	100	0	99	93	101	80	86	91.8	8.81476	91.8	8.81476
PAH	benzo(g,h,i)perylene	100	0	76	85	89	81	74	81	6.204837	81	6.204837
PAH	Sum PAHs	1700	0	1670	1730	1639	1543	1477	1611.8	101.2457	94.81176	5.955632
PAH	Sum of Commonly Detected	700	0	664	674	679	626	620	652.6	27.63693	93.22857	193.4585
Flame Retardant	TCEP	100		86	80	82	74	129	90.2	22.11787	90.2	22.11787
Flame Retardant	TDCPP	100		75	128	118	131	123	115	22.90196	115	22.90196
Pyrethroid	Bifenthrin	100		102	102	109	92	96	100.2	6.496153	100.2	6.496153
Pyrethroid	Cypermethrin	100		97	95	99	90	91	94.4	3.847077	94.4	3.847077
Pyrethroid	lambda cyhalothrin	100		113	114	134	98	103	112.4	13.83112	112.4	13.83112

Surrogate recovery from soil samples. Average recovery 89.8% ± 15%

Class	p terph	% Recovery
Horticulture Pavilion OKC -DS	181	90.5
Horticulture Pavilion OKC-A	166	83
Physical Plant Admin. Bldg - DS	202	101
Physical Plant Admin. Bldg - A	192	96
Allen Suites - DS	216	108
Allen Suites - A	185	92.5
BAE Bioenergy Lab - DS	204	102
BAE Bioenergy Lab - A	185	92.5
Construction Technology Lab - DS	171	85.5
Construction Technology Lab - A	154	77
Kubat House - DS	181	90.5
Kubat House - A	174	87
Career Tech - DS	179	89.5
Career Tech - A	129	64.5
Bleden - DS	207	103.5
Belden - A	150	75
Jones Vilage - DS	200	100
Jones Village - A	160	80
Thatcher - DS	181	90.5
Thatcher - A	175	87.5
Storm House - DS	186	93
Storm Barn - A	126	63
Public Information Building - DS	154	77
Public Information Building - A	159	79.5
Fire Protection Safety Lab - A	168	84
BAE Lab - DS	195	97.5
BAE Lab - A	176	88
Physical Plant North - DS	216	108
Physical Plant North - A	170	85
HSEC OKC - DS	197	98.5
HSEC OKC - A	197	98.5
Agriculture Resource Center OKC - DS	247	123.5
Agriculture Resource Center OKC - A	160	80
Storm Barn - DS	167	83.5
Fire Protection Lab - DS	190	95
Allen - DS Replicate	248	124
Physical Plant Administration - DS Replicate	247	123.5
Horticulture Pavilion OKC - DS Replicate	216	108
Clean 6	152	76
s1	149	74.5
s2	146	73
s3	144	72
s4	141	70.5
s5	157	78.5

APPENDIX D

CONTINUOUS CONDUCTIVITY DATA

Downspout Mixing Rhodamine Testing

Run 1

Flowrate 0.741 gpm

Sample	RFU	PPB	Time (min)	Notes
Bucket 1	36693.09	142	-	Rhod. Concentration we want to reach is 36693 RFU
1	2104.29	8	0.00	0.741 gpm flowrate
2	1797.28	6	0.25	
3	2826	10	0.50	Bucket Empty at 6:45
4	1857.31	7	0.75	
5	1801.91	6	1.00	
6	1803.97	6	1.25	
7	1798.17	6	1.50	
8	1706.28	6	1.75	
9	4678.91	18	2.00	
10	8860.56	34	2.25	
11	11512.35	44	2.50	
12	13423.6	52	3.00	
13	15001.81	58	3.50	
14	12578.25	48	4.00	
15	22010.9	85	4.50	
16	24105.8	93	5.00	
17	23932.98	93	5.50	
18	28711.98	111	6.00	
19	31991.87	124	6.50	
20	36321.67	141	7.00	

Run 2

Flowrate 1.00 gpm

Sample	RFU	PPB	Time (min)	Notes
Bucket 2	42707.05	166	-	Bucket 3 RFU changed from 50705.97 to 31656.04 by the time experiment ran since added RWT to water
Bucket 3	39249.6		-	Therefore, can assume Bucket 2 RFU also changed from intial reading, which is why we could not get that high of level of RFU in samples
1	approx 1500	5	0.00	Fluorometer did not save readings for samples 1-11, but they followed same trend as samples in run 1
2	-		0.50	
3	-		1.00	
4	-		1.50	
5	-		2.00	
6	-		2.50	
7	-		3.00	
8	approx 5000	19	3.25	
9	-		3.50	
10	-		3.75	
11	-		4.00	
12	25364.86	98	4.25	
13	30624.51	119	4.50	
14	31470.33	122	4.75	
15	32962.87	128	5.00	1st 5 gallon bucket empty after 5 minutes (Bucket 2), switched to Bucket 3
16	32478.83	126	5.25	
17	33356.35	129	5.50	
18	37282.4	145	5.75	
19	38709.4	150	6.00	
20	38969.47	151	6.25	
21	36203.65	141	6.50	
22	38725.62	150	6.75	
23	38073.61	148	7.00	
24	38297.73	149	7.25	
25	38051.32	148	7.50	
26	38623.42	150	7.75	

Run 3

Flowrate 2.56 gpm

Sample	RFU	PPB	Time (min)	Notes
Bucket 4	31656.04	123	-	Used two new buckets
Bucket 5	35606.71	138	-	Took about 3 minutes to become completely mix
1	2109	8	0.00	
2	2049.97	7	0.25	
3	2553.2	9	0.50	
4	2670.38	10	0.75	
5	3997.38	15	1.00	
6	21243.14	82	1.25	
7	26291.4	102	1.50	
8	28345.46	110	1.75	
9	29500.13	114	2.00	1st 5 gallon bucket empty at 1:57 (bucket 4), switched to bucket 5
10	29229.16	113	2.25	
11	28883.72	112	2.50	
12	30182.64	117	2.75	
13	33651.1	131	3.00	
14	34108.89	132	3.25	
15	33755.25	131	3.50	
16	34865.06	135	3.75	Bucket 5 empty at 3:54

Asphalt Shingle	4/11/2012		4/13/2012		4/19/2012		5/11/2012		5/29/2012		6/6/2012		7/9/2012	
Time (min)	**EC Rain**	**Runoff Volume (L)**	**EC Rain**	**Runoff Volume (L)**	**EC Rain**	**Runoff Volume (L)**	**EC Rain**	**Runoff Volume (L)**	**EC Rain**	**Runoff Volume (L)**	**EC Rain**	**Runoff Volume (L)**	**EC Rain**	**Runoff Volume (L)**
1	138	6	133	4	52	7	107	2	115	4	133	12.9	752	1.84
2	128	7	131	6	56	11	105	2	69	9	126	16.6	747	1.84
3	112	7	118	6	57	17	124	2	71	14	115	20.2	745	1.84
4	102	7	119	7	50	20	140	4	16	19	96	25.7	720	1.84
5	91	9	104	9	41	24	147	4	13	35	83	29.4	717	1.84
6	87	9	94	9	34	26	150	4	10	51	83	34.9	730	3.68
7	77	11	77	11	30	29	153	4	10	61	69	39.1	730	3.68
8	70	11	65	11	24	31	154	4	9	70	30	44.3	730	5.52
9	62	13	60	13	21	33	152	4	9	77	26	48.1	729	5.52
10	50	15	51	15	18	35	150	6	8	87	17	50.9	732	5.52
11	43	15	41	17	17	37	147	6	8	94	22	51.9	735	5.52
12	34	17	37	17	17	37	143	6	8	99	25	52.9	742	5.52
13	29	17	31	18	17	37	139	6	9	107	28	52.9	626	5.52
14	28	18	27	20	17	39	138	6	9	111	26	53.9	558	7.36
15	27	22	26	22	17	39	138	6	9	113	34	54.9	581	11.03
16	22	24	23	22	17	40	136	6	10	114	28	54.9	528	12.87
17	17	29	21	24	18	42	135	7	10	115	29	54.9	530	14.71
18	14	31	20	26	18	42	135	7	10	115	32	54.9	528	14.71
19	12	33	19	26	19	42	130	7	10	115	30	54.9	487	14.71
20	11	33	18	28	19	42	127	7	10	115	27	54.9	392	14.71
21	11	33	18	28	19	44	124	7	10	115	30	54.9	399	14.71
22	10	33	17	29	19	44	120	7	10	115	30	54.9	327	14.71
23	10	33	16	29	19	44	115	9	10	115	30	54.9	332	16.55
24	10	33	16	29	19	44	109	9	10	115	30	54.9	334	18.39
25	10	33	16	29	19	46	109	9	10	115	30	58.6	327	18.39
26	10	33	15	31	20	46	99	9	10	115	30	59.6	303	20.23
27	11	33	15	31	20	46	102	9	11	115	29	59.6	303	20.23
28	11	33	16	31	20	48	93	9	11	115	29	59.6	282	20.23
29	11	33	16	31	20	48	93	9	11	115	29	59.6	278	20.23
30	12	33	16	33	21	50	92	9	11	115	24	59.6	283	20.23
31	12	33	16	33	21	50	91	9	11	115	26	59.6	284	20.23
32	12	35	17	33	21	50	91	11	11	115	29	59.6	284	20.23
33	12	35	17	33	22	50	90	11	12	115	29	59.6	280	20.23
34	12	35	18	35	22	51	90	11	12	115	29	59.6	261	20.23
35	12	35	18	35	22	51	89	11	12	115	29	59.6	210	20.23
36	12	35	19	35	21	51	88	11	12	115	29	59.6		
37	12	35	19	37	22	51	88	11	12	115	29	59.6		
38	12	35	20	39	22	51	75	11	13	115	29	59.6		
39	12	35	20	39	22	51	77	13	13	115	29	59.6		
40	13	35	19	44	22	51	72	13	13	115	29	59.6		
41	13	35	18	46	22	51	71	13	13	115	28	59.6		
42	13	35	16	46	22	51	71	13	13	115	30	59.6		
43	13	37	15	46	22	51	72	15	13	115	31	59.6		
44	14	37	15	48	22	51	70	15	13	115	30	59.6		
45	14	37	14	50	22	53	55	15	13	115	30	59.6		
46	15	37	15	50	23	53	48	15	13	115	27	62.4		
47	16	37	15	50	23	53	42	15	13	115	28	63.4		
48	17	37	15	50	23	53	41	15	13	115	28	64.4		
49	17	37	15	51	23	53	41	17	14	115	28	64.4		
50	15	37	16	51	23	53	46	17	15	115	28	64.4		
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Metal	4/3/2012		4/13/2012		4/19/2012		4/28/2012		5/20/2012		5/29/2012		6/6/2012		6/15/2012		7/9/2012	
Time (min)	**EC Rain**	**Runoff Volume (L)**	**EC Rain**	**Runoff Volume (L)**	**EC Rain**	**Runoff Volume (L)**	**EC Rain**	**Runoff Volume (L)**	**EC Rain**	**Runoff Volume (L)**	**EC Rain**	**Runoff Volume (L)**	**EC Rain**	**Runoff Volume (L)**	**EC Rain**	**Runoff Volume (L)**	**EC Rain**	**Runoff Volume (L)**
1	71	0	82	5	136	91	135	16	143	3	153	40	121	41	635	107	766	8
2	71	0	84	11	112	97	136	24	143	8	96	40	78	59	628	111	751	15
3	70	0	86	16	90	112	95	35	143	14	66	40	51	86	636	121	732	15
4	70	0	86	21	55	130	69	46	144	22	18	40	43	110	635	141	739	15
5	67	0	84	25	56	150	60	64	144	36	20	40	46	137	619	161	657	15
6	67	0	84	31	42	176	56	81	144	45	23	94	37	157	558	189	691	15
7	67	0	84	35	31	200	54	91	143	51	18	94	29	201	188	224	595	15
8	66	0	84	37	27	219	53	94	143	56	17	94	25	266	165	256	546	23
9	67	0	84	39	25	232	50	94	142	64	18	160	21	323	167	286	564	23
10	66	0	84	41	22	244	49	94	136	65	8	160	13	373	138	313	566	26
11	66	0	84	44	20	255	49	94	133	66	15	187	17	418	108	339	552	30
12	64	0	84	50	18	255	48	95	60	71	12	200	13	457	147	369	566	32
13	62	0	84	56	15	255	48	96	69	77	12	214	13	488	81	398	571	35
14	60	0	84	59	16	255	48	96	49	85	11	227	10	516	67	427	592	37
15	63	0	76	59	14	255	48	96	48	94	10	227	10	536	31	467	613	38
16	64	0	64	63	13	263	49	96	36	110	10	227	7	552	58	510	350	39
17	65	0	65	66	14	263	50	96	37	129	10	227	9	566	58	555	80	41
18	64	0	64	66	12	263	46	96	32	146	10	227	8	577	20	604	99	46
19	64	0	63	66	11	263	44	96	22	167	10	241	8	585	25	672	383	53
20	64	0	55	66	11	263	44	99	22	188	10	241	8	592	22	761	403	59
21	63	0	39	66	11	263	44	109	19	208	11	241	8	597	25	864	315	62
22	63	0	30	66	11	263	44	115	14	224	10	241	8	602	27	973	278	65
23	61	0	25	66	11	268	45	115	15	239	11	241	8	606	19	1077	235	67
24	60	0	23	66	11	273	45	115	14	250	11	241	8	609	11	1181	218	68
25	59	0	24	66	11	273	45	115	13	260	10	241	8	612	8	1300	200	69
26	57	0	18	66	11	273	45	115	13	269	10	241	8	613	7	1411	126	70
27	56	0	18	66	12	279	45	115	12	275	10	241	8	616	7	1514	88	70
28	56	0	19	66	12	279	45	115	12	280	10	241	8	622	7	1599	80	70
29	56	0	11	66	12	279	44	115	12	285	10	241	8	629	8	1687	76	70
30	56	0	14	66	12	284	44	115	12	289	10	241	8	635	8	1761	69	70
31	54	0	13	66	12	284	44	115	12	293	10	241	13	639	8	1816	66	70
32	53	0	17	66	12	284	44	115	12	297	10	241	14	643	9	1876	74	70
33	53	0	12	66	12	284	44	115	12	300	10	241	14	645	13	1945	58	70
34	53	0	12	66	12	290	44	115	12	304	10	241	14	647	12	2007	59	70
35	54	0	12	66	12	290	44	115	12	308	10	241	14	647	9	2069	57	70
36	55	0	13	66	12	290	44	115	12	313	10	241	14	648	9	2121	53	70
37	56	0	13	66	12	290	45	115	14	318	10	241	14	648	8	2164	52	70
38	56	0	13	68	13	290	45	115	14	322	10	241	14	648	9	2199	52	70
39	56	0	18	84	13	290	45	115	14	326	10	241	14	649	9	2237	52	70
40	57	0	17	88	12	290	44	115	14	329	10	241	14	650	9	2267	53	70
41	57	0	17	119	12	290	45	115	15	332	11	241	14	650	9	2285	52	70
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417	23	170
418	24	175
419	24	181
420	24	185
421	24	191
422	24	198
423	24	206
424	24	213
425	24	220
426	22	231
427	18	247
428	16	265
429	14	282
430	11	300
431	8	318
432	8	335
433	9	353
434	9	370

435	9	386
436	9	400
437	11	412
438	14	423
439	16	434
440	16	443
441	16	452
442	17	461
443	17	467
444	18	473
445	20	479
446	11	484
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481	9	622
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486	10	681
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489	10	710
490	10	720
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492	10	739
493	10	748
494	10	758
495	10	768
496	10	779
497	10	791
498	10	802
499	10	814
500	10	825
501	10	836
502	10	847
503	10	856
504	10	864
505	10	870

Tar & Gravel	4/13/2012		4/19/2012		4/28/2012		5/11/2012		5/20/2012		5/29/2012		6/6/2012		6/15/2012		7/9/2012	
Time (min)	**EC Rain**	**Runoff Volume (L)**	**EC Rain**	**Runoff Volume (L)**	**EC Rain**	**Runoff Volume (L)**	**EC Rain**	**Runoff Volume (L)**	**EC Rain**	**Runoff Volume (L)**	**EC Rain**	**Runoff Volume (L)**	**EC Rain**	**Runoff Volume (L)**	**EC Rain**	**Runoff Volume (L)**	**EC Rain**	**Runoff Volume (L)**
1	45	40	47	0	96	3	86	0	162	4	45	31	493	4	357	4	751	20
2	43	63	44	25	95	5	87	0	191	8	33	31	490	6	357	11	749	20
3	41	64	39	56	96	11	87	0	137	13	56	59	488	8	357	15	749	20
4	43	72	39	88	94	11	87	0	113	31	43	93	485	11	354	19	749	22
5	41	84	37	88	94	11	87	0	77	52	30	127	480	14	347	21	748	25
6	39	97	38	90	93	11	87	0	72	75	21	158	468	16	336	25	748	28
7	38	110	36	92	93	11	84	0	71	95	19	185	171	18	196	27	748	28
8	37	123	36	94	93	11	81	0	62	109	19	202	161	19	134	52	748	28
9	37	133	34	95	92	11	79	0	67	111	18	216	156	20	122	83	747	28
10	35	142	34	96	92	11	79	0	53	111	16	225	170	21	118	112	733	28
11	35	151	35	96	93	11	79	0	59	111	16	231	107	23	72	130	685	28
12	35	159	34	97	92	15	79	0	56	111	16	233	103	25	86	137	625	28
13	35	166	34	97	92	19	79	0	54	111	18	235	79	26	64	139	467	28
14	35	174	34	97	92	25	80	0	51	111	18	236	95	28	88	142	399	28
15	35	180	33	97	92	27	79	0	50	111	17	237	65	29	77	142	366	28
16	35	186	33	97	92	33	80	0	45	111	18	237	66	29	56	142	245	28
17	35	191	33	97	92	37	79	0	45	111	18	237	57	30	63	142	237	28
18	35	191	33	97	91	41	79	0	46	111	19	237	50	30	53	143	198	28
19	35	191	33	97	91	44	79	0	45	111	19	237	50	30	39	147	199	28
20	35	191	34	97	91	47	79	0	44	111	19	237	49	30	26	151	201	28
21	35	191	34	97	92	50	79	0	44	111	20	237	50	30	28	158	202	28
22	35	191	34	97	92	53	79	0	43	111	20	237	51	30	28	169	198	28
23	35	191	34	97	91	55	78	0	44	111	21	237	50	30	16	178	196	28
24	35	191	34	97	91	58	76	0	44	111	21	237	49	30	19	192	186	28
25	34	191	34	97	92	61	75	0	47	111	22	237	52	30	12	205	182	28
26	34	191	34	97	92	64	74	0	47	111	22	237	56	30	12	220	185	28
27	33	191	34	97	92	66	74	0	46	111	22	237	47	30	11	229	184	28
28	33	191	34	97	92	69	73	0	46	111	23	237	39	30	11	237	168	28
29	32	191	34	97	93	69	74	0	46	111	24	237	39	30	10	243	169	28
30	31	191	34	97	93	72	72	0	46	111	25	237	39	30	10	248	167	28
31	30	191	34	97	93	72	70	0	46	111	26	237	39	30	10	253	165	28
32	30	191	34	97	93	72	69	0	46	111	26	237	39	30	10	257	164	28
33	30	191	34	97	93	72	70	0	46	111	27	237	40	30	10	260	160	28
34	28	191	34	97	93	72	69	0	46	111	27	237	40	30	10	262	153	28
35	28	191	34	97	93	72	68	0	46	111	27	237	40	30	10	264	151	28
36	27	192	34	97	93	72	69	0	47	111	27	237	40	30	11	265	151	28
37	27	192	34	97	93	72	69	0	47	111	27	237	40	30	10	266	142	28
38	27	192	34	97	93	75	66	0	47	111	27	237	37	30	11	267	151	28
39	27	192	35	97	93	75	52	0	47	111	27	237	36	31	11	267	155	28
40	27	192	36	97	93	75	48	0	47	111	31	237	35	32	11	267	140	28
41	30	192	36	97	93	75	48	0	47	111	32	237	35	32	11	267	136	28
42	30	192	36	97	93	75	47	0	47	111	32	237	35	32	11	267	135	28
43	30	192	36	97	93	75	47	7	47	111	32	237	35	32	11	267	135	28
44	30	192	36	97	93	75	48	7	47	111	32	237	35	33	11	267	134	28
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92	35	218	41	97	87	119		60	111	55	237						
93	35	259	41	97	87	119		60	111	57	237						
94	35	309	41	97	88	120		60	111	57	237						
95	27	363	41	97	88	121		60	111	58	237						
96	20	418	41	97	88	121		60	111	58	237						
97	18	472	41	97	89	122		60	111	59	237						
98	19	527	41	97	90	123		60	111	59	237						
99	16	582	41	97	90	123		59	111	60	237						
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101	15	688	41	97	90	124		59	111	61	237						
102	13	740	41	97	90	124		59	111	61	237						
103	12	785	41	97	89	124		59	111	61	237						
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105	11	866	41	97	88	125		58	111	62	237						
106	11	901	41	97	88	125		58	111	62	237						
107	10	929	41	97	86	125		58	111	62	240						
108	10	953	41	97	85	125		58	111	63	244						
109	10	974	41	97	85	125		57	111	64	247						
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200	21	1058	63	97
201	21	1058	63	97
202	21	1058	64	97
203	21	1058	77	97
204	21	1058	80	97
205	22	1058	81	97
206	23	1058	81	97
207			81	97
208			81	97
209			81	97
210			82	97

APPENDIX E

SPEARMAN'S RHO CORRELATION RESULTS

Critical Student's T and Spearman's Rho (r_s) values for SIM correlation matrices (α=0.05).

Correlation Matrix	**n**	**df (n-2)**	**Student's t**	**Critical r_s value**
Inorganics – All Simulations, All Roofs	323	321	1.646	0.091
Organics – All Simulations, All Roofs	215	213	1.646	0.112
Inorganics – 64 mm/hr, All Roofs	108	106	1.659	0.159
Organics – 64 mm/hr, All Roofs	72	70	1.667	0.195
Inorganics – 38 mm/hr, All Roofs	108	106	1.659	0.159
Organics – 38 mm/hr, All Roofs	72	70	1.667	0.195
Inorganics – 28 mm/hr, All Roofs	107	105	1.660	0.160
Organics – 28 mm/hr, All Roofs	71	69	1.667	0.197
Inorganics – Asphalt, All Simulations	108	106	1.659	0.159
Organics – Asphalt, All Simulations	72	70	1.667	0.195
Inorganics – Clay Tile, All Simulations	108	106	1.659	0.159
Organics – Clay Tile, All Simulations	72	70	1.667	0.195
Inorganics – Metal, All Simulations	107	105	1.660	0.160
Organics – Metal, All Simulations	71	69	1.667	0.197

Critical Student's t and Spearman's Rho (r_s) values for OKC correlation matrices (α=0.05).

Correlation Matrix	**n**	**df (n-2)**	**Student's t**	**Critical r_s value**
All Roofs – Inorganics & Organics	82	80	1.664	0.183
All Roofs – Bacteria Samples	41	39	1.685	0.261
A_{OKC} – Inorganics & Organics	21	19	1.729	0.369
A_{OKC} – Bacteria	13	11	1.796	0.476
M_{OKC} – Inorganics & Organics	39	37	1.687	0.267
M_{OKC} – Bacteria	18	16	1.746	0.400
TG – Inorganics & Organics	22	20	1.725	0.360
TG – Bacteria	10	8	1.860	0.549

All Roofs, All Simulations

Results for: Simulation_CensoredData_CorrelationMatrix.MTW

Spearman Rho: pH, EC, NO3N, SAR, B, Fe, Cu, Zn, ...

	pH	EC	NO3N	SAR
EC	0.434			
NO3N	0.282	0.719		
SAR	0.101	0.335	0.010	
B	-0.211	0.234	0.257	0.152
Fe	-0.017	0.511	0.545	0.011
Cu	-0.167	0.496	0.411	0.092
Zn	-0.030	0.380	0.304	0.119
Mn	-0.117	0.227	0.271	0.051
TSS	0.589	0.659	0.555	-0.119
Turbidity	0.384	0.663	0.654	-0.105
Total PAHs	-0.089	0.351	0.523	-0.232
Commonly Detecte	0.109	0.629	0.664	-0.144
Carcinogenic PAH	0.109	0.559	0.662	-0.207
>300 RL, Total P	0.109	0.459	0.592	-0.117
>75 RL, Commonly	0.126	0.570	0.686	-0.162
>70 RL, Carcinog	0.128	0.574	0.684	-0.144
TCEP	0.008	0.260	0.283	-0.082
TDCPP	-0.014	0.579	0.398	0.215
Bifenthrin	-0.068	-0.077	-0.064	-0.033
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	0.106	0.644	0.666	-0.109
Benzo(a)pyrene_P	0.171	0.607	0.725	-0.170

	B	Fe	Cu	Zn
Fe	0.413			
Cu	0.355	0.412		
Zn	0.329	0.553	0.286	
Mn	0.687	0.443	0.443	0.257
TSS	*	0.326	0.344	0.091
Turbidity	0.206	0.420	0.398	0.268
Total PAHs	0.251	0.500	0.369	0.267
Commonly Detecte	0.277	0.568	0.445	0.382
Carcinogenic PAH	0.296	0.575	0.466	0.321
>300 RL, Total P	0.360	0.477	0.302	0.338
>75 RL, Commonly	0.322	0.598	0.432	0.366
>70 RL, Carcinog	0.336	0.581	0.432	0.358
TCEP	-0.029	0.367	0.104	0.183
TDCPP	0.230	0.520	0.259	0.604
Bifenthrin	-0.012	-0.032	-0.035	-0.038
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	0.270	0.567	0.420	0.408
Benzo(a)pyrene_P	0.323	0.625	0.423	0.352

	Mn	TSS	Turbidity	Total PAHs
TSS	0.156			
Turbidity	0.186	0.638		
Total PAHs	0.263	0.560	0.371	
Commonly Detecte	0.279	0.764	0.596	0.840
Carcinogenic PAH	0.302	0.765	0.606	0.839
>300 RL, Total P	0.207	0.553	0.411	0.699
>75 RL, Commonly	0.305	0.690	0.567	0.804
>70 RL, Carcinog	0.321	0.689	0.542	0.786
TCEP	-0.041	*	0.167	0.236
TDCPP	0.147	0.167	0.349	0.207
Bifenthrin	-0.017	0.025	0.035	0.045
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	0.265	0.729	0.578	0.828
Benzo(a)pyrene_P	0.339	0.731	0.588	0.804

	Commonly Detecte	Carcinogenic PAH	>300 RL, Total P	>75 RL, Commonly

Carcinogenic PAH	0.933			
>300 RL, Total P	0.740	0.778		
>75 RL, Commonly	0.861	0.905	0.860	
>70 RL, Carcinog	0.836	0.880	0.885	0.971
TCEP	0.258	0.275	0.340	0.301
TDCPP	0.359	0.232	0.220	0.267
Bifenthrin	0.039	0.046	-0.033	-0.043
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	0.981	0.887	0.748	0.866
Benzo(a)pyrene_P	0.867	0.913	0.844	0.976

	>70 RL, Carcinog	TCEP	TDCPP	Bifenthrin
TCEP	0.314			
TDCPP	0.273	0.287		
Bifenthrin	-0.041	-0.012	-0.044	
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	0.843	0.265	0.406	0.033
Benzo(a)pyrene_P	0.960	0.307	0.267	-0.044

	Cypermethrin	Lambda Cyhalothr	Fluoranthene_PAH
Lambda Cyhalothr	*		
Fluoranthene_PAH	*	*	
Benzo(a)pyrene_P	*	*	0.866

Cell Contents: Spearman rho

* NOTE * All values in column are identical.

August Simulation, All Roofs (No TSS Data)

Results for: AugustSimulations_CorrelationMatrix.MTW

Spearman Rho: pH, EC, NO3N, SAR, B, Fe, Cu, Zn, ...

	pH	EC	NO3N	SAR
EC	-0.381			
NO3N	-0.273	0.790		
SAR	0.057	-0.602	-0.442	
B	-0.396	0.397	0.419	0.029
Fe	-0.449	0.712	0.713	-0.329
Cu	-0.665	0.475	0.378	-0.140
Zn	-0.404	0.640	0.583	-0.239
Mn	-0.423	0.407	0.430	-0.015
Turbidity	-0.338	0.766	0.611	-0.467
Total PAHs	-0.403	0.773	0.692	-0.455
Commonly Detecte	-0.475	0.878	0.749	-0.545
Carcinogenic PAH	-0.437	0.855	0.773	-0.482
>300 RL, Total P	-0.247	0.755	0.748	-0.383
>75 RL, Commonly	-0.364	0.829	0.801	-0.438
>70 RL, Carcinog	-0.341	0.815	0.788	-0.415
TCEP	0.007	0.344	0.376	-0.314
TDCPP	-0.265	0.566	0.542	-0.516
Bifenthrin	*	*	*	*
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	-0.435	0.858	0.737	-0.540
Benzo(a)pyrene_P	-0.367	0.829	0.801	-0.442

	B	Fe	Cu	Zn
Fe	0.510			
Cu	0.482	0.515		
Zn	0.441	0.716	0.414	
Mn	0.930	0.544	0.516	0.463
Turbidity	0.341	0.586	0.450	0.526
Total PAHs	0.379	0.791	0.465	0.720
Commonly Detecte	0.387	0.788	0.458	0.749
Carcinogenic PAH	0.425	0.839	0.512	0.715

>300 RL, Total P	0.486	0.794	0.279	0.671
>75 RL, Commonly	0.446	0.876	0.443	0.717
>70 RL, Carcinog	0.457	0.859	0.416	0.709
TCEP	-0.091	0.355	0.050	0.109
TDCPP	0.013	0.464	0.255	0.462
Bifenthrin	*	*	*	*
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	0.362	0.770	0.405	0.735
Benzo(a)pyrene_P	0.447	0.877	0.446	0.719

	Mn	Turbidity	Total PAHs	Commonly Detecte
Turbidity	0.292			
Total PAHs	0.386	0.639		
Commonly Detecte	0.396	0.709	0.900	
Carcinogenic PAH	0.435	0.718	0.880	0.918
>300 RL, Total P	0.433	0.614	0.781	0.792
>75 RL, Commonly	0.456	0.681	0.852	0.868
>70 RL, Carcinog	0.468	0.656	0.843	0.857
TCEP	-0.099	0.255	0.342	0.344
TDCPP	0.080	0.506	0.517	0.570
Bifenthrin	*	*	*	*
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	0.371	0.697	0.892	0.993
Benzo(a)pyrene_P	0.458	0.682	0.851	0.868

	Carcinogenic PAH	>300 RL, Total P	>75 RL, Commonly	>70 RL, Carcinog
>300 RL, Total P	0.858			
>75 RL, Commonly	0.941	0.912		
>70 RL, Carcinog	0.929	0.923	0.987	
TCEP	0.373	0.438	0.396	0.402
TDCPP	0.400	0.246	0.401	0.376
Bifenthrin	*	*	*	*
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	0.891	0.790	0.866	0.854
Benzo(a)pyrene_P	0.940	0.912	1.000	0.987

	TCEP	TDCPP	Bifenthrin	Cypermethrin
TDCPP	0.223			
Bifenthrin	*	*		
Cypermethrin	*	*	*	
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	0.357	0.586	*	*
Benzo(a)pyrene_P	0.401	0.404	*	*

	Lambda Cyhalothr	Fluoranthene_PAH
Fluoranthene_PAH	*	
Benzo(a)pyrene_P	*	0.865

Cell Contents: Spearman rho

* NOTE * All values in column are identical.

November Simulation, All Roofs

Results for: NovemberSimulations_CorrelationMatrix.MTW

Spearman Rho: pH, EC, NO3N, SAR, B, Fe, Cu, Zn, ...

	pH	EC	NO3N	SAR
EC	0.336			
NO3N	0.233	0.604		
SAR	0.005	-0.198	-0.147	
B	*	*	*	*
Fe	0.342	0.393	0.459	-0.048
Cu	0.015	0.464	0.328	-0.060
Zn	0.062	-0.082	-0.115	-0.070

Mn	0.217	0.289	0.325	-0.033
TSS	0.473	0.708	0.533	-0.212
Turbidity	0.324	0.579	0.666	-0.243
Total PAHs	0.381	0.581	0.704	-0.176
Commonly Detecte	0.417	0.712	0.668	-0.152
Carcinogenic PAH	0.404	0.702	0.655	-0.148
>300 RL, Total P	0.360	0.274	0.309	-0.051
>75 RL, Commonly	0.309	0.561	0.601	-0.115
>70 RL, Carcinog	0.322	0.602	0.603	-0.102
TCEP	*	*	*	*
TDCPP	0.084	-0.132	-0.037	-0.080
Bifenthrin	*	*	*	*
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	0.409	0.659	0.707	-0.135
Benzo(a)pyrene_P	0.400	0.644	0.684	-0.127

	B	Fe	Cu	Zn
Fe	*			
Cu	*	0.245		
Zn	*	0.210	-0.059	
Mn	*	0.509	0.425	-0.082
TSS	*	0.419	0.341	0.114
Turbidity	*	0.321	0.298	-0.102
Total PAHs	*	0.426	0.306	-0.072
Commonly Detecte	*	0.470	0.402	-0.032
Carcinogenic PAH	*	0.480	0.422	-0.019
>300 RL, Total P	*	0.089	0.047	0.078
>75 RL, Commonly	*	0.405	0.340	0.049
>70 RL, Carcinog	*	0.366	0.391	0.014
TCEP	*	*	*	*
TDCPP	*	0.009	-0.162	0.308
Bifenthrin	*	*	*	*
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	*	0.507	0.282	0.004
Benzo(a)pyrene_P	*	0.505	0.313	0.008

	Mn	TSS	Turbidity	Total PAHs
TSS	0.285			
Turbidity	0.186	0.659		
Total PAHs	0.292	0.619	0.613	
Commonly Detecte	0.336	0.755	0.670	0.867
Carcinogenic PAH	0.343	0.739	0.659	0.849
>300 RL, Total P	-0.059	0.370	0.317	0.436
>75 RL, Commonly	0.290	0.614	0.618	0.809
>70 RL, Carcinog	0.323	0.639	0.637	0.754
TCEP	*	*	*	*
TDCPP	-0.093	0.141	0.028	-0.050
Bifenthrin	*	*	*	*
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	0.351	0.705	0.671	0.875
Benzo(a)pyrene_P	0.373	0.696	0.648	0.860

	Commonly Detecte	Carcinogenic PAH	>300 RL, Total P	>75 RL, Commonly
Carcinogenic PAH	0.983			
>300 RL, Total P	0.462	0.467		
>75 RL, Commonly	0.866	0.876	0.533	
>70 RL, Carcinog	0.800	0.813	0.575	0.924
TCEP	*	*	*	*
TDCPP	-0.018	-0.016	-0.080	-0.011
Bifenthrin	*	*	*	*
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	0.947	0.923	0.487	0.909
Benzo(a)pyrene_P	0.917	0.928	0.501	0.938

	>70 RL, Carcinog	TCEP	TDCPP	Bifenthrin
TCEP	*			
TDCPP	0.014	*		

Bifenthrin	*	*	*	
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	0.835	*	0.021	*
Benzo(a)pyrene_P	0.874	*	0.031	*

	Cypermethrin	Lambda Cyhalothr	Fluoranthene_PAH
Lambda Cyhalothr	*		
Fluoranthene_PAH	*	*	
Benzo(a)pyrene_P	*	*	0.965

Cell Contents: Spearman rho

* NOTE * All values in column are identical.

February Simulation, All Roofs

Results for: FebruarySimulations_CorrelationMatrix.MTW

Spearman Rho: pH, EC, NO3N, SAR, B, Fe, Cu, Zn, ...

	pH	EC	NO3N	SAR
EC	0.910			
NO3N	0.492	0.585		
SAR	*	*	*	
B	*	*	*	*
Fe	0.203	0.201	0.322	*
Cu	0.205	0.347	0.507	*
Zn	-0.034	-0.126	0.002	*
Mn	-0.048	-0.075	-0.058	*
TSS	0.758	0.737	0.576	*
Turbidity	0.642	0.701	0.542	*
Total PAHs	0.641	0.696	0.693	*
Commonly Detecte	0.724	0.803	0.755	*
Carcinogenic PAH	0.694	0.785	0.768	*
>300 RL, Total P	0.656	0.747	0.863	*
>75 RL, Commonly	0.676	0.759	0.834	*
>70 RL, Carcinog	0.672	0.755	0.848	*
TCEP	*	*	*	*
TDCPP	0.157	0.169	0.231	*
Bifenthrin	-0.017	0.012	-0.064	*
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	0.725	0.806	0.767	*
Benzo(a)pyrene_P	0.673	0.755	0.848	*

	B	Fe	Cu	Zn
Fe	*			
Cu	*	-0.042		
Zn	*	-0.034	0.069	
Mn	*	-0.019	0.429	0.277
TSS	*	0.182	0.345	0.017
Turbidity	*	0.197	0.368	-0.051
Total PAHs	*	0.210	0.437	0.021
Commonly Detecte	*	0.220	0.454	0.015
Carcinogenic PAH	*	0.225	0.461	0.023
>300 RL, Total P	*	0.269	0.502	0.084
>75 RL, Commonly	*	0.252	0.479	0.065
>70 RL, Carcinog	*	0.257	0.487	0.068
TCEP	*	*	*	*
TDCPP	*	-0.020	-0.042	-0.029
Bifenthrin	*	-0.020	-0.042	-0.029
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	*	0.231	0.466	0.026
Benzo(a)pyrene_P	*	0.277	0.482	0.068

	Mn	TSS	Turbidity	Total PAHs
TSS	-0.003			
Turbidity	0.030	0.687		

Total PAHs	-0.035	0.784	0.749	
Commonly Detecte	-0.107	0.843	0.823	0.896
Carcinogenic PAH	-0.100	0.841	0.815	0.871
>300 RL, Total P	-0.071	0.765	0.645	0.779
>75 RL, Commonly	-0.076	0.790	0.694	0.805
>70 RL, Carcinog	-0.074	0.777	0.664	0.793
TCEP	*	*	*	*
TDCPP	-0.014	0.199	0.047	0.157
Bifenthrin	-0.014	0.050	0.157	0.052
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	-0.100	0.824	0.800	0.889
Benzo(a)pyrene_P	-0.074	0.776	0.668	0.792

	Commonly Detecte	Carcinogenic PAH	>300 RL, Total P	>75 RL, Commonly
Carcinogenic PAH	0.971			
>300 RL, Total P	0.840	0.859		
>75 RL, Commonly	0.871	0.889	0.965	
>70 RL, Carcinog	0.856	0.876	0.981	0.983
TCEP	*	*	*	*
TDCPP	0.176	0.174	0.202	0.202
Bifenthrin	0.063	0.064	-0.071	-0.076
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	0.976	0.936	0.859	0.889
Benzo(a)pyrene_P	0.855	0.873	0.980	0.982

	>70 RL, Carcinog	TCEP	TDCPP	Bifenthrin
TCEP	*			
TDCPP	0.198	*		
Bifenthrin	-0.074	*	-0.014	
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	0.873	*	0.180	0.071
Benzo(a)pyrene_P	0.997	*	0.221	-0.074

	Cypermethrin	Lambda Cyhalothr	Fluoranthene_PAH
Lambda Cyhalothr	*		
Fluoranthene_PAH	*	*	
Benzo(a)pyrene_P	*	*	0.875

Cell Contents: Spearman rho

* NOTE * All values in column are identical.

Asphalt Shingle, All Simulations

Results for: AS_CorrelationMatrix_Data

Spearman Rho: pH, EC, NO3N, SAR, B, Fe, Cu, Zn, ...

	pH	EC	NO3N	SAR
EC	0.053			
NO3N	-0.104	0.800		
SAR	-0.319	0.349	0.147	
B	-0.389	0.397	0.435	0.343
Fe	-0.339	0.558	0.559	0.335
Cu	-0.146	0.842	0.812	0.277
Zn	-0.458	0.537	0.487	0.488
Mn	-0.226	0.420	0.485	0.211
TSS	0.295	0.533	0.531	*
Turbidity	0.081	0.671	0.708	0.074
Total PAHs	-0.324	0.502	0.610	0.018
Commonly Detecte	-0.232	0.677	0.681	0.142
Carcinogenic PAH	-0.197	0.636	0.697	0.038
>300 RL, Total P	-0.280	0.555	0.617	0.135
>75 RL, Commonly	-0.184	0.692	0.751	0.073
>70 RL, Carcinog	-0.195	0.721	0.749	0.111
TCEP	*	*	*	*

TDCPP	-0.427	0.547	0.386	0.476
Bifenthrin	-0.083	-0.157	-0.115	-0.053
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	-0.253	0.696	0.676	0.196
Benzo(a)pyrene_P	-0.157	0.717	0.770	0.079

	B	Fe	Cu	Zn
Fe	0.626			
Cu	0.443	0.586		
Zn	0.586	0.803	0.543	
Mn	0.756	0.677	0.522	0.472
TSS	*	0.256	0.653	*
Turbidity	0.351	0.432	0.633	0.353
Total PAHs	0.417	0.443	0.654	0.374
Commonly Detecte	0.448	0.529	0.754	0.475
Carcinogenic PAH	0.469	0.516	0.757	0.434
>300 RL, Total P	0.601	0.364	0.661	0.363
>75 RL, Commonly	0.496	0.554	0.759	0.451
>70 RL, Carcinog	0.534	0.553	0.783	0.450
TCEP	*	*	*	*
TDCPP	0.432	0.739	0.497	0.868
Bifenthrin	-0.036	-0.063	-0.108	-0.063
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	0.432	0.526	0.735	0.499
Benzo(a)pyrene_P	0.517	0.552	0.776	0.437

	Mn	TSS	Turbidity	Total PAHs
TSS	0.269			
Turbidity	0.332	0.620		
Total PAHs	0.441	0.700	0.563	
Commonly Detecte	0.491	0.770	0.646	0.936
Carcinogenic PAH	0.512	0.798	0.696	0.926
>300 RL, Total P	0.433	0.562	0.481	0.695
>75 RL, Commonly	0.544	0.724	0.684	0.865
>70 RL, Carcinog	0.583	0.774	0.666	0.842
TCEP	*	*	*	*
TDCPP	0.372	*	0.323	0.280
Bifenthrin	-0.048	0.005	0.003	0.026
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	0.468	0.702	0.606	0.912
Benzo(a)pyrene_P	0.576	0.717	0.703	0.846

	Commonly Detecte	Carcinogenic PAH	>300 RL, Total P	>75 RL, Commonly
Carcinogenic PAH	0.969			
>300 RL, Total P	0.694	0.702		
>75 RL, Commonly	0.904	0.913	0.768	
>70 RL, Carcinog	0.865	0.878	0.799	0.957
TCEP	*	*	*	*
TDCPP	0.396	0.348	0.201	0.359
Bifenthrin	-0.009	0.003	-0.058	-0.096
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	0.980	0.921	0.697	0.896
Benzo(a)pyrene_P	0.890	0.902	0.764	0.985

	>70 RL, Carcinog	TCEP	TDCPP	Bifenthrin
TCEP	*			
TDCPP	0.353	*		
Bifenthrin	-0.086	*	-0.072	
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	0.859	*	0.436	-0.026
Benzo(a)pyrene_P	0.961	*	0.332	-0.093

	Cypermethrin	Lambda Cyhalothr	Fluoranthene_PAH
Lambda Cyhalothr	*		
Fluoranthene_PAH	*	*	
Benzo(a)pyrene_P	*	*	0.875

Cell Contents: Spearman rho

* NOTE * All values in column are identical.

Clay Tile, All Simulations

Results for: CT_CorrelationMatrix_Data.MTW

Spearman Rho: pH, EC, NO3N, SAR, B, Fe, Cu, Zn, ...

	pH	EC	NO3N	SAR
EC	0.677			
NO3N	0.559	0.712		
SAR	0.164	0.356	-0.051	
B	*	*	*	*
Fe	0.111	0.449	0.483	-0.119
Cu	-0.019	0.202	0.059	0.159
Zn	-0.061	0.358	0.331	-0.035
Mn	*	*	*	*
TSS	0.677	0.682	0.631	-0.153
Turbidity	0.639	0.605	0.757	-0.211
Total PAHs	0.138	0.197	0.501	-0.355
Commonly Detecte	0.376	0.602	0.764	-0.259
Carcinogenic PAH	0.410	0.516	0.721	-0.309
>300 RL, Total P	0.278	0.412	0.633	-0.229
>75 RL, Commonly	0.372	0.510	0.717	-0.259
>70 RL, Carcinog	0.369	0.512	0.718	-0.259
TCEP	-0.030	0.435	0.451	-0.134
TDCPP	0.113	0.688	0.523	0.186
Bifenthrin	*	*	*	*
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	0.388	0.636	0.790	-0.223
Benzo(a)pyrene_P	0.441	0.573	0.772	-0.279

	B	Fe	Cu	Zn
Fe	*			
Cu	*	0.315		
Zn	*	0.572	0.307	
Mn	*	*	*	*
TSS	*	0.330	-0.037	*
Turbidity	*	0.368	0.110	0.114
Total PAHs	*	0.503	0.183	0.324
Commonly Detecte	*	0.585	0.081	0.457
Carcinogenic PAH	*	0.596	0.123	0.351
>300 RL, Total P	*	0.579	0.190	0.434
>75 RL, Commonly	*	0.605	0.163	0.397
>70 RL, Carcinog	*	0.611	0.163	0.403
TCEP	*	0.646	0.352	0.524
TDCPP	*	0.527	0.216	0.560
Bifenthrin	*	*	*	*
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	*	0.607	0.097	0.478
Benzo(a)pyrene_P	*	0.634	0.145	0.380

	Mn	TSS	Turbidity	Total PAHs
TSS	*			
Turbidity	*	0.628		
Total PAHs	*	0.549	0.280	
Commonly Detecte	*	0.756	0.524	0.741
Carcinogenic PAH	*	0.734	0.529	0.769
>300 RL, Total P	*	0.474	0.390	0.676
>75 RL, Commonly	*	0.636	0.498	0.733
>70 RL, Carcinog	*	0.636	0.498	0.733
TCEP	*	*	0.277	0.396
TDCPP	*	0.458	0.270	0.260
Bifenthrin	*	*	*	*

Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	*	0.734	0.528	0.717
Benzo(a)pyrene_P	*	0.718	0.553	0.758

	Commonly Detecte	Carcinogenic PAH	>300 RL, Total P	>75 RL, Commonly
Carcinogenic PAH	0.888			
>300 RL, Total P	0.763	0.834		
>75 RL, Commonly	0.828	0.906	0.921	
>70 RL, Carcinog	0.828	0.906	0.921	0.999
TCEP	0.462	0.515	0.585	0.557
TDCPP	0.497	0.305	0.296	0.347
Bifenthrin	*	*	*	*
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	0.966	0.827	0.789	0.854
Benzo(a)pyrene_P	0.865	0.947	0.881	0.957

	>70 RL, Carcinog	TCEP	TDCPP	Bifenthrin
TCEP	0.569			
TDCPP	0.351	0.492		
Bifenthrin	*	*	*	
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	0.854	0.484	0.539	*
Benzo(a)pyrene_P	0.957	0.546	0.356	*

	Cypermethrin	Lambda Cyhalothr	Fluoranthene_PAH
Lambda Cyhalothr	*		
Fluoranthene_PAH	*	*	
Benzo(a)pyrene_P	*	*	0.888

Cell Contents: Spearman rho

* NOTE * All values in column are identical.

Metal, All Simulations

Results for: M_CorrelationMatrix_Data.MTW

Spearman Rho: pH, EC, NO3N, SAR, B, Fe, Cu, Zn, ...

	pH	EC	NO3N	SAR
EC	0.639			
NO3N	0.380	0.642		
SAR	0.146	0.385	-0.052	
B	*	*	*	*
Fe	0.182	0.489	0.615	-0.186
Cu	-0.051	0.131	0.212	-0.002
Zn	0.151	0.476	0.445	-0.086
Mn	0.026	-0.005	0.075	-0.080
TSS	0.748	0.684	0.551	-0.088
Turbidity	0.600	0.735	0.630	0.018
Total PAHs	0.030	0.237	0.444	-0.335
Commonly Detecte	0.392	0.594	0.672	-0.283
Carcinogenic PAH	0.385	0.497	0.675	-0.307
>300 RL, Total P	0.298	0.397	0.563	-0.265
>75 RL, Commonly	0.350	0.463	0.637	-0.286
>70 RL, Carcinog	0.317	0.433	0.602	-0.275
TCEP	-0.092	0.200	0.212	-0.063
TDCPP	0.013	0.553	0.331	0.007
Bifenthrin	*	*	*	*
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	0.390	0.586	0.651	-0.276
Benzo(a)pyrene_P	0.390	0.485	0.664	-0.296

	B	Fe	Cu	Zn
Fe	*			

Cu	*	0.267		
Zn	*	0.508	0.219	
Mn	*	0.179	0.323	0.056
TSS	*	0.371	0.084	0.308
Turbidity	*	0.448	0.146	0.433
Total PAHs	*	0.541	0.120	0.253
Commonly Detecte	*	0.633	0.097	0.441
Carcinogenic PAH	*	0.699	0.130	0.387
>300 RL, Total P	*	0.545	0.150	0.319
>75 RL, Commonly	*	0.667	0.147	0.392
>70 RL, Carcinog	*	0.601	0.151	0.358
TCEP	*	0.294	0.496	0.213
TDCPP	*	0.249	0.045	0.491
Bifenthrin	*	*	*	*
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	*	0.599	0.083	0.442
Benzo(a)pyrene_P	*	0.717	0.142	0.368

	Mn	TSS	Turbidity	Total PAHs
TSS	0.072			
Turbidity	-0.004	0.608		
Total PAHs	0.113	0.428	0.155	
Commonly Detecte	0.026	0.756	0.530	0.796
Carcinogenic PAH	0.047	0.744	0.506	0.781
>300 RL, Total P	-0.087	0.620	0.410	0.730
>75 RL, Commonly	-0.094	0.702	0.487	0.762
>70 RL, Carcinog	-0.091	0.664	0.449	0.747
TCEP	-0.021	*	0.158	0.174
TDCPP	-0.117	0.058	0.503	0.074
Bifenthrin	*	*	*	*
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	-0.006	0.752	0.521	0.788
Benzo(a)pyrene_P	0.054	0.752	0.496	0.773

	Commonly Detecte	Carcinogenic PAH	>300 RL, Total P	>75 RL, Commonly
Carcinogenic PAH	0.902			
>300 RL, Total P	0.826	0.915		
>75 RL, Commonly	0.867	0.960	0.953	
>70 RL, Carcinog	0.847	0.939	0.975	0.977
TCEP	0.205	0.229	0.243	0.239
TDCPP	0.315	0.144	0.155	0.115
Bifenthrin	*	*	*	*
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	0.997	0.888	0.826	0.859
Benzo(a)pyrene_P	0.885	0.980	0.931	0.978

	>70 RL, Carcinog	TCEP	TDCPP	Bifenthrin
TCEP	0.245			
TDCPP	0.135	0.114		
Bifenthrin	*	*	*	
Cypermethrin	*	*	*	*
Lambda Cyhalothr	*	*	*	*
Fluoranthene_PAH	0.846	0.184	0.335	*
Benzo(a)pyrene_P	0.957	0.234	0.095	*

	Cypermethrin	Lambda Cyhalothr	Fluoranthene_PAH
Lambda Cyhalothr	*		
Fluoranthene_PAH	*	*	
Benzo(a)pyrene_P	*	*	0.869

Cell Contents: Spearman rho

* NOTE * All values in column are identical.

All Roofs, All Events

Results for: OKC_CorrelationMatrix_Data.MTW

Spearman Rho: ADP, pH, EC, NO3N, SAR, B, Fe, Cu, ...

	ADP	pH	EC	NO3N
pH	0.038			
EC	0.201	0.669		
NO3N	0.161	0.449	0.832	
SAR	0.302	-0.092	0.352	0.338
B	0.109	0.165	0.356	0.337
Fe	-0.047	0.077	0.112	0.040
Cu	-0.076	0.241	0.382	0.261
Zn	0.244	-0.062	0.147	0.253
Mn	0.003	0.126	0.369	0.189
TSS	0.179	0.320	0.428	0.188
Turbidity	0.341	0.392	0.635	0.704
Total Coliforms	-0.336	0.327	-0.148	-0.182
E. coli	-0.237	0.541	0.147	0.026
Total PAHs	0.067	0.185	0.290	0.065
Common PAHs	0.027	0.173	0.289	0.066
Carcinogenic PAH	0.023	0.203	0.319	0.096
T. PAHs >300 RL	0.027	0.161	0.319	0.141
Common PAHs>75	-0.013	0.141	0.253	0.052
Carcin PAHs>70	-0.044	0.157	0.279	0.069
TCEP	0.338	0.135	0.309	0.316
TDCPP	0.277	0.266	0.435	0.458
Bifenthrin	*	*	*	*
Cypermenthrin	*	*	*	*
LambdaChyalothri	0.146	-0.029	0.141	0.145
Fluoranthene	0.004	0.085	0.206	0.030
Benzo(a)pyrene	-0.023	0.186	0.289	0.060

	SAR	B	Fe	Cu
B	0.319			
Fe	-0.132	0.108		
Cu	0.097	0.394	0.236	
Zn	0.088	0.149	0.423	0.166
Mn	0.209	0.513	0.281	0.393
TSS	-0.041	0.227	0.212	0.353
Turbidity	0.197	0.244	0.161	0.237
Total Coliforms	-0.273	-0.181	0.152	0.086
E. coli	-0.372	-0.116	0.440	0.023
Total PAHs	0.028	0.311	0.036	0.398
Common PAHs	0.035	0.283	0.053	0.388
Carcinogenic PAH	0.036	0.271	0.060	0.378
T. PAHs >300 RL	0.014	0.364	0.157	0.448
Common PAHs>75	0.012	0.291	0.079	0.405
Carcin PAHs>70	0.007	0.243	0.050	0.339
TCEP	0.246	0.191	-0.096	0.071
TDCPP	0.154	-0.123	-0.022	0.071
Bifenthrin	*	*	*	*
Cypermenthrin	*	*	*	*
LambdaChyalothri	-0.070	-0.064	0.191	0.221
Fluoranthene	0.031	0.304	0.055	0.376
Benzo(a)pyrene	-0.000	0.296	0.093	0.400

	Zn	Mn	TSS	Turbidity
Mn	-0.017			
TSS	-0.010	0.361		
Turbidity	0.209	0.199	0.607	
Total Coliforms	-0.152	0.061	-0.080	-0.068
E. coli	0.068	-0.039	0.171	0.292
Total PAHs	-0.110	0.401	0.764	0.417
Common PAHs	-0.100	0.386	0.760	0.413
Carcinogenic PAH	-0.094	0.387	0.745	0.418
T. PAHs >300 RL	0.005	0.469	0.709	0.387
Common PAHs>75	-0.094	0.398	0.730	0.381
Carcin PAHs>70	-0.098	0.377	0.716	0.378
TCEP	-0.085	0.280	0.065	0.235
TDCPP	0.224	0.030	0.144	0.472
Bifenthrin	*	*	*	*
Cypermenthrin	*	*	*	*

LambdaChyalothri	0.035	0.065	0.349	0.354
Fluoranthene	-0.101	0.381	0.701	0.358
Benzo(a)pyrene	-0.085	0.412	0.733	0.373

	Total Coliforms	E. coli	Total PAHs	Common PAHs
E. coli	0.349			
Total PAHs	-0.065	0.080		
Common PAHs	-0.073	0.070	0.989	
Carcinogenic PAH	-0.061	0.093	0.978	0.991
T. PAHs >300 RL	-0.044	0.026	0.855	0.843
Common PAHs>75	-0.065	0.090	0.957	0.971
Carcin PAHs>70	-0.059	0.114	0.921	0.933
TCEP	-0.319	-0.241	-0.020	-0.053
TDCPP	-0.033	0.283	0.013	0.039
Bifenthrin	*	*	*	*
Cypermenthrin	*	*	*	*
LambdaChyalothri	-0.170	0.030	0.277	0.287
Fluoranthene	-0.072	0.046	0.941	0.945
Benzo(a)pyrene	-0.078	0.114	0.940	0.949

	Carcinogenic PAH	T. PAHs >300 RL	Common PAHs>75	Carcin PAHs>70
T. PAHs >300 RL	0.831			
Common PAHs>75	0.962	0.868		
Carcin PAHs>70	0.942	0.869	0.961	
TCEP	-0.046	0.000	-0.060	-0.092
TDCPP	0.050	-0.059	0.016	0.038
Bifenthrin	*	*	*	*
Cypermenthrin	*	*	*	*
LambdaChyalothri	0.275	0.315	0.266	0.267
Fluoranthene	0.918	0.878	0.968	0.917
Benzo(a)pyrene	0.957	0.865	0.971	0.971

	TCEP	TDCPP	Bifenthrin	Cypermenthrin
TDCPP	0.280			
Bifenthrin	*	*		
Cypermenthrin	*	*	*	
LambdaChyalothri	0.086	0.216	*	*
Fluoranthene	-0.064	-0.001	*	*
Benzo(a)pyrene	-0.045	-0.005	*	*

	LambdaChyalothri	Fluoranthene
Fluoranthene	0.275	
Benzo(a)pyrene	0.258	0.924

Cell Contents: Spearman rho

* NOTE * All values in column are identical.

OKC Tar & Gravel (MS), All Events

Results for: OKC_MS_CorrelationMatrix.MTW

Spearman Rho: ADP, pH, EC, NO3N, SAR, B, Fe, Cu, ...

	ADP	pH	EC	NO3N
pH	0.303			
EC	0.292	0.948		
NO3N	0.439	0.892	0.944	
SAR	0.297	0.656	0.569	0.522
B	*	*	*	*
Fe	-0.505	-0.238	-0.196	-0.150
Cu	0.203	-0.147	-0.076	0.069
Zn	0.143	-0.242	-0.251	-0.063
Mn	-0.211	-0.017	0.120	0.018
TSS	-0.209	-0.089	-0.057	-0.060
Turbidity	0.275	0.161	0.298	0.374
Total Coliforms	-0.616	0.569	0.600	0.233
E. coli	-0.528	0.334	0.426	0.354
Total PAHs	-0.014	-0.115	-0.069	-0.088
Common PAHs	-0.014	-0.098	-0.051	-0.072
Carcinogenic PAH	-0.001	-0.098	-0.049	-0.074

T. PAHs >300 RL	-0.116	-0.377	-0.302	-0.283
Common PAHs>75	0.097	-0.169	-0.092	-0.100
Carcin PAHs>70	0.047	-0.196	-0.156	-0.200
TCEP	0.602	0.450	0.517	0.631
TDCPP	0.518	0.430	0.443	0.483
Bifenthrin	*	*	*	*
Cypermenthrin	*	*	*	*
LambdaChyalothri	0.000	-0.258	-0.258	-0.231
Fluoranthene	0.047	-0.032	0.018	-0.042
Benzo(a)pyrene	0.022	-0.257	-0.167	-0.187

	SAR	B	Fe	Cu
B	*			
Fe	-0.424	*		
Cu	-0.159	*	0.246	
Zn	-0.075	*	0.542	0.641
Mn	0.021	*	-0.092	-0.102
TSS	-0.306	*	0.508	0.174
Turbidity	-0.141	*	0.200	0.303
Total Coliforms	0.570	*	-0.826	-0.419
E. coli	0.010	*	-0.313	0.058
Total PAHs	-0.092	*	0.162	0.177
Common PAHs	-0.078	*	0.168	0.198
Carcinogenic PAH	-0.103	*	0.137	0.114
T. PAHs >300 RL	-0.490	*	0.228	0.152
Common PAHs>75	-0.174	*	0.135	0.253
Carcin PAHs>70	-0.203	*	0.041	-0.028
TCEP	0.202	*	-0.476	0.000
TDCPP	0.185	*	-0.380	0.283
Bifenthrin	*	*	*	*
Cypermenthrin	*	*	*	*
LambdaChyalothri	-0.396	*	0.220	0.409
Fluoranthene	-0.070	*	0.093	0.175
Benzo(a)pyrene	-0.182	*	0.063	0.070

	Zn	Mn	TSS	Turbidity
Mn	-0.284			
TSS	0.170	0.328		
Turbidity	0.225	0.327	0.666	
Total Coliforms	-0.733	0.359	-0.342	-0.394
E. coli	-0.319	0.407	0.131	0.334
Total PAHs	0.126	0.294	0.699	0.653
Common PAHs	0.138	0.294	0.697	0.657
Carcinogenic PAH	0.067	0.294	0.667	0.633
T. PAHs >300 RL	0.197	0.490	0.597	0.554
Common PAHs>75	0.128	0.328	0.626	0.715
Carcin PAHs>70	-0.014	0.354	0.622	0.643
TCEP	-0.265	-0.117	-0.266	0.193
TDCPP	0.006	0.214	0.250	0.650
Bifenthrin	*	*	*	*
Cypermenthrin	*	*	*	*
LambdaChyalothri	0.372	-0.048	0.362	0.361
Fluoranthene	0.104	0.354	0.605	0.686
Benzo(a)pyrene	0.018	0.328	0.564	0.585

	Total Coliforms	E. coli	Total PAHs	Common PAHs
E. coli	0.351			
Total PAHs	-0.427	0.396		
Common PAHs	-0.427	0.396	0.999	
Carcinogenic PAH	-0.425	0.438	0.989	0.987
T. PAHs >300 RL	-0.485	0.217	0.599	0.599
Common PAHs>75	-0.477	0.408	0.894	0.895
Carcin PAHs>70	-0.477	0.408	0.830	0.819
TCEP	*	*	-0.093	-0.093
TDCPP	-0.038	0.717	0.363	0.376
Bifenthrin	*	*	*	*
Cypermenthrin	*	*	*	*
LambdaChyalothri	-0.419	0.058	0.363	0.363
Fluoranthene	-0.394	0.422	0.819	0.830
Benzo(a)pyrene	-0.477	0.408	0.875	0.864

	Carcinogenic PAH	T. PAHs >300 RL	Common PAHs>75	Carcin PAHs>70
T. PAHs >300 RL	0.600			
Common PAHs>75	0.893	0.670		
Carcin PAHs>70	0.832	0.722	0.915	
TCEP	-0.037	-0.213	-0.108	-0.174
TDCPP	0.340	0.329	0.411	0.410
Bifenthrin	*	*	*	*
Cypermenthrin	*	*	*	*
LambdaChyalothri	0.363	0.605	0.405	0.437
Fluoranthene	0.810	0.722	0.928	0.894
Benzo(a)pyrene	0.887	0.670	0.906	0.922

	TCEP	TDCPP	Bifenthrin	Cypermenthrin
TDCPP	0.388			
Bifenthrin	*	*		
Cypermenthrin	*	*	*	
LambdaChyalothri	-0.117	0.303	*	*
Fluoranthene	-0.174	0.535	*	*
Benzo(a)pyrene	-0.079	0.281	*	*

	LambdaChyalothri	Fluoranthene
Fluoranthene	0.437	
Benzo(a)pyrene	0.405	0.818

Cell Contents: Spearman rho

* NOTE * All values in column are identical.

OKC Metal (HP), All Events

Results for: OKC_HP_CorrelationMatrix.MTW

Spearman Rho: ADP, pH, EC, NO3N, SAR, B, Fe, Cu, ...

	ADP	pH	EC	NO3N
pH	0.302			
EC	0.313	0.530		
NO3N	0.072	0.183	0.797	
SAR	0.273	-0.269	0.300	0.385
B	*	*	*	*
Fe	-0.005	-0.054	-0.274	-0.401
Cu	-0.329	-0.124	0.000	0.073
Zn	0.160	-0.350	0.050	0.102
Mn	*	*	*	*
TSS	0.396	0.566	0.514	0.192
Turbidity	0.397	0.499	0.710	0.645
Total Coliforms	-0.322	-0.306	-0.539	-0.395
E. coli	-0.109	-0.016	0.002	-0.281
Total PAHs	0.232	0.482	0.399	0.138
Common PAHs	0.212	0.459	0.403	0.140
Carcinogenic PAH	0.238	0.479	0.441	0.188
T. PAHs >300 RL	0.108	0.335	0.341	0.163
Common PAHs>75	0.080	0.388	0.336	0.124
Carcin PAHs>70	0.118	0.398	0.425	0.214
TCEP	0.065	0.245	0.190	0.215
TDCPP	0.452	0.117	0.502	0.496
Bifenthrin	*	*	*	*
Cypermenthrin	*	*	*	*
LambdaChyalothri	0.130	0.042	0.236	0.239
Fluoranthene	0.092	0.309	0.247	0.062
Benzo(a)pyrene	0.142	0.434	0.391	0.150

	SAR	B	Fe	Cu
B	*			
Fe	-0.043	*		
Cu	0.033	*	-0.116	
Zn	0.110	*	0.078	0.094
Mn	*	*	*	*
TSS	0.028	*	-0.065	0.171

Turbidity	0.359	*	-0.271	0.093
Total Coliforms	-0.203	*	-0.089	0.398
E. coli	0.210	*	0.333	-0.108
Total PAHs	-0.018	*	-0.064	0.228
Common PAHs	0.005	*	-0.008	0.228
Carcinogenic PAH	0.056	*	-0.012	0.218
T. PAHs >300 RL	-0.073	*	0.077	0.152
Common PAHs>75	-0.018	*	0.073	0.239
Carcin PAHs>70	0.045	*	0.049	0.239
TCEP	0.088	*	-0.236	-0.135
TDCPP	0.429	*	-0.269	-0.078
Bifenthrin	*	*	*	*
Cypermenthrin	*	*	*	*
LambdaChyalothri	0.029	*	0.092	-0.054
Fluoranthene	-0.025	*	0.067	0.239
Benzo(a)pyrene	-0.005	*	0.094	0.244

	Zn	Mn	TSS	Turbidity
Mn	*			
TSS	-0.008	*		
Turbidity	-0.017	*	0.704	
Total Coliforms	0.083	*	-0.196	-0.321
E. coli	0.047	*	-0.100	-0.156
Total PAHs	0.081	*	0.737	0.531
Common PAHs	0.115	*	0.747	0.517
Carcinogenic PAH	0.145	*	0.725	0.539
T. PAHs >300 RL	0.204	*	0.626	0.444
Common PAHs>75	0.141	*	0.683	0.450
Carcin PAHs>70	0.225	*	0.688	0.510
TCEP	-0.358	*	0.075	0.254
TDCPP	0.071	*	0.391	0.462
Bifenthrin	*	*	*	*
Cypermenthrin	*	*	*	*
LambdaChyalothri	0.001	*	0.216	0.267
Fluoranthene	0.137	*	0.655	0.418
Benzo(a)pyrene	0.173	*	0.711	0.485

	Total Coliforms	E. coli	Total PAHs	Common PAHs
E. coli	-0.500			
Total PAHs	0.058	0.053		
Common PAHs	0.058	0.053	0.981	
Carcinogenic PAH	0.036	0.080	0.966	0.990
T. PAHs >300 RL	0.170	0.002	0.820	0.819
Common PAHs>75	0.115	0.132	0.926	0.952
Carcin PAHs>70	0.068	0.183	0.897	0.905
TCEP	-0.381	-0.157	-0.102	-0.124
TDCPP	-0.326	-0.198	0.212	0.228
Bifenthrin	*	*	*	*
Cypermenthrin	*	*	*	*
LambdaChyalothri	-0.381	-0.157	0.087	0.118
Fluoranthene	0.123	0.167	0.928	0.929
Benzo(a)pyrene	0.042	0.213	0.904	0.926

	Carcinogenic PAH	T. PAHs >300 RL	Common PAHs>75	Carcin PAHs>70
T. PAHs >300 RL	0.813			
Common PAHs>75	0.947	0.860		
Carcin PAHs>70	0.911	0.892	0.950	
TCEP	-0.098	-0.130	-0.145	-0.139
TDCPP	0.251	0.124	0.170	0.211
Bifenthrin	*	*	*	*
Cypermenthrin	*	*	*	*
LambdaChyalothri	0.107	0.082	0.034	0.034
Fluoranthene	0.911	0.857	0.961	0.901
Benzo(a)pyrene	0.932	0.863	0.972	0.966

	TCEP	TDCPP	Bifenthrin	Cypermenthrin
TDCPP	0.422			
Bifenthrin	*	*		
Cypermenthrin	*	*	*	
LambdaChyalothri	0.154	0.304	*	*
Fluoranthene	-0.148	0.150	*	*

Benzo(a)pyrene	-0.107	0.185	*	*

	LambdaChyalothri	Fluoranthene
Fluoranthene	0.023	
Benzo(a)pyrene	0.051	0.926

Cell Contents: Spearman rho

* NOTE * All values in column are identical.

OKC Asphalt Shingle (AS), All Events

Results for: OKC_AS_CorrelationMatrix.MTW

Spearman Rho: ADP, pH, EC, NO3N, SAR, B, Fe, Cu, ...

	ADP	pH	EC	NO3N
pH	-0.143			
EC	0.338	0.539		
NO3N	0.478	0.111	0.673	
SAR	0.269	0.134	0.764	0.643
B	0.317	0.300	0.681	0.631
Fe	0.557	-0.051	0.471	0.381
Cu	0.172	0.619	0.745	0.455
Zn	0.695	-0.064	0.668	0.672
Mn	0.316	0.088	0.613	0.409
TSS	0.508	0.218	0.507	0.318
Turbidity	0.575	-0.156	0.415	0.728
Total Coliforms	0.198	0.412	-0.053	-0.077
E. coli	0.139	0.322	-0.030	-0.041
Total PAHs	0.135	0.297	0.607	0.437
Common PAHs	0.067	0.252	0.516	0.362
Carcinogenic PAH	0.056	0.236	0.506	0.331
T. PAHs >300 RL	0.149	0.343	0.669	0.516
Common PAHs>75	0.067	0.252	0.516	0.362
Carcin PAHs>70	0.040	0.231	0.496	0.327
TCEP	0.578	-0.136	0.557	0.479
TDCPP	0.155	-0.400	-0.061	0.003
Bifenthrin	*	*	*	*
Cypermenthrin	*	*	*	*
LambdaChyalothri	0.395	-0.021	0.115	0.158
Fluoranthene	0.055	0.168	0.467	0.371
Benzo(a)pyrene	0.029	0.338	0.574	0.296

	SAR	B	Fe	Cu
B	0.753			
Fe	0.303	0.153		
Cu	0.556	0.501	0.327	
Zn	0.755	0.716	0.489	0.428
Mn	0.620	0.490	0.616	0.397
TSS	0.104	0.200	0.472	0.307
Turbidity	0.380	0.461	0.418	0.287
Total Coliforms	-0.410	-0.427	0.297	0.105
E. coli	-0.361	-0.188	0.284	0.000
Total PAHs	0.395	0.441	0.304	0.498
Common PAHs	0.346	0.361	0.199	0.421
Carcinogenic PAH	0.321	0.340	0.204	0.383
T. PAHs >300 RL	0.428	0.449	0.348	0.508
Common PAHs>75	0.346	0.361	0.199	0.421
Carcin PAHs>70	0.309	0.321	0.181	0.363
TCEP	0.599	0.409	0.666	0.316
TDCPP	0.239	-0.157	0.078	0.091
Bifenthrin	*	*	*	*
Cypermenthrin	*	*	*	*
LambdaChyalothri	-0.100	-0.198	0.336	0.114
Fluoranthene	0.337	0.361	0.187	0.398
Benzo(a)pyrene	0.356	0.361	0.186	0.463

	Zn	Mn	TSS	Turbidity

Mn	0.571			
TSS	0.369	0.367		
Turbidity	0.560	0.308	0.538	
Total Coliforms	-0.339	-0.211	0.073	0.058
E. coli	-0.277	-0.354	0.124	0.047
Total PAHs	0.291	0.450	0.760	0.579
Common PAHs	0.203	0.372	0.718	0.567
Carcinogenic PAH	0.187	0.357	0.733	0.543
T. PAHs >300 RL	0.296	0.458	0.754	0.595
Common PAHs>75	0.203	0.372	0.718	0.567
Carcin PAHs>70	0.166	0.338	0.723	0.536
TCEP	0.759	0.751	0.390	0.311
TDCPP	0.232	0.128	-0.107	0.094
Bifenthrin	*	*	*	*
Cypermenthrin	*	*	*	*
LambdaChyalothri	0.100	-0.013	0.453	0.489
Fluoranthene	0.221	0.336	0.663	0.633
Benzo(a)pyrene	0.185	0.373	0.729	0.487

	Total Coliforms	E. coli	Total PAHs	Common PAHs
E. coli	0.777			
Total PAHs	-0.147	-0.060		
Common PAHs	-0.172	-0.094	0.981	
Carcinogenic PAH	-0.147	-0.060	0.978	0.993
T. PAHs >300 RL	-0.057	0.028	0.982	0.956
Common PAHs>75	-0.172	-0.094	0.981	1.000
Carcin PAHs>70	-0.169	-0.084	0.970	0.990
TCEP	-0.339	-0.277	0.277	0.182
TDCPP	-0.290	-0.277	-0.074	-0.020
Bifenthrin	*	*	*	*
Cypermenthrin	*	*	*	*
LambdaChyalothri	0.180	0.191	0.244	0.287
Fluoranthene	-0.172	-0.104	0.948	0.978
Benzo(a)pyrene	-0.191	-0.124	0.971	0.979

	Carcinogenic PAH	T. PAHs >300 RL	Common PAHs>75	Carcin PAHs>70
T. PAHs >300 RL	0.954			
Common PAHs>75	0.993	0.956		
Carcin PAHs>70	0.999	0.950	0.990	
TCEP	0.165	0.282	0.182	0.146
TDCPP	-0.048	-0.153	-0.020	-0.048
Bifenthrin	*	*	*	*
Cypermenthrin	*	*	*	*
LambdaChyalothri	0.244	0.249	0.287	0.245
Fluoranthene	0.961	0.921	0.978	0.959
Benzo(a)pyrene	0.984	0.951	0.979	0.982

	TCEP	TDCPP	Bifenthrin	Cypermenthrin
TDCPP	0.294			
Bifenthrin	*	*		
Cypermenthrin	*	*	*	
LambdaChyalothri	0.146	0.329	*	*
Fluoranthene	0.169	-0.018	*	*
Benzo(a)pyrene	0.161	-0.061	*	*

	LambdaChyalothri	Fluoranthene
Fluoranthene	0.333	
Benzo(a)pyrene	0.241	0.939

Cell Contents: Spearman rho

* NOTE * All values in column are identical.

VITA

Jessica Jeanette Lay

Candidate for the Degree of

Master of Science

Thesis: WATER QUALITY AND THE FIRST-FLUSH EFFECT IN ROOF-BASED RAINWATER HARVESTING

Major Field: Biosystems Engineering

Biographical:

Education: Completed the requirements for the Master of Science in Biosystems Engineering at Oklahoma State University, Stillwater, Oklahoma in May, 2014. Completed the requirements for the Bachelor of Science in Biosystems Engineering, Minor in Soil Science, and College Honors Award in Engineering, Architecture, and Technology at Oklahoma State University, Stillwater, Oklahoma in May, 2010.

Experience: Intern for the Water Quality Division at the Oklahoma Department of Environmental Quality in Oklahoma City, OK; 2012-2013 Fulbright U.S. Student Research Fellow to Sierra Leone, West Africa; 2010 NSF Graduate Research Fellow & Research Assistant at Oklahoma State University; Teaching Assistant for Fluid Mechanics, BAE Environment and Natural Resources, and BAE Physical Properties of Biological Material at Oklahoma State University; Environmental Health and Safety Intern at General Electric Aviation in Arkansas City, KS; Water Management Intern for Woolpert, Inc. in Columbia, SC; 2008 Wentz Research Scholar and 2007 Woolpert Research Scholar at Oklahoma State University.

Professional Memberships: American Society of Agricultural and Biological Engineering, American Water Works Association